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CELL MODULE AND FUEL CONDITIONER

3RD QUARTERLY REPORT: APRIL-JUNE, 1980

D.Q. Hoover, Jr.
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Westinghouse Electric Corporation
Pittsburgh, PA. 15235

July, 1980

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lewis Research Center
Under Contract DEN 3-161

for
U.S. DEPARTMENT OF ENERGY
Energy Technology
Division of Fossil Fuel Utilization
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N80 31882

**CELL MODULE AND FUEL CONDITIONER
DEVELOPMENT: 3RD QUARTERLY REPORT**

**WESTINGHOUSE ELECTRIC CORPORATION
PITTSBURG, PA**

JUL 80

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I. INTRODUCTION

This report is for the second Phase of a six Phase program to develop commercially viable on-site integrated energy systems (OS/IES) using phosphoric acid fuel cell (PAFC) modules to convert fuel to electricity. Phase II is a planned two year effort to develop appropriate fuel cell module and fuel conditioner conceptual designs. The fuel cell module development effort comprises three coordinated tasks:

Task 1: Design of Large Cell Stacks

Task 2: Stack Fabrication

Task 3: Stack Testing

The "Fuel Conditioner Subsystem Development" task is the fourth technical task of this effort. Provision for "Management, Reporting and Documentation" is included as a fifth task.

The work accomplished during this reporting period is described at the subtask level in the following section.

II. TECHNICAL PROGRESS

1.1 Detailed Analytical Model

A detailed model for the MK-2 bipolar plate design was developed and a computer code that has not been completely debugged was written. The model calculates the distribution of current density and temperature within a group of cells containing a cooling plate. Local concentrations of reactants are also calculated throughout the active area of the cell. The heat transfer model includes the cooling effects of reactant and cooling gas streams. Debugging is expected to be completed during the next quarter.

A simplified theory of the effect of catalyst distribution on cell performance was developed. Additional analysis is required to determine whether significant performance improvement can be obtained with appropriate catalyst distribution.

1.2 Stack Design

A decision was made in conjunction with the NASA Project Manager to use an ERC proprietary matrix, designated as Mat-1, in stack 560 and all subsequent stacks. A modification to improve manifold sealing and a new method for fastening the terminal studs to the current collector was devised.

Mat-1 - ERC has developed a new type of matrix, designated Mat-1,* which has smaller pores and a more uniform pore size distribution and thus, higher bubble pressure than Kynol. The smaller pore size promotes retention of acid in the matrix and minimizes reactant crossover and the material is capable of withstanding higher temperatures than Kynol.

Extensive experience with Mat-1 matrices has been accumulated at ERC under an in-house program, the DOE Technology Program and Army programs. Current plans call for this matrix to be used in Stack 560 and all subsequent stacks.

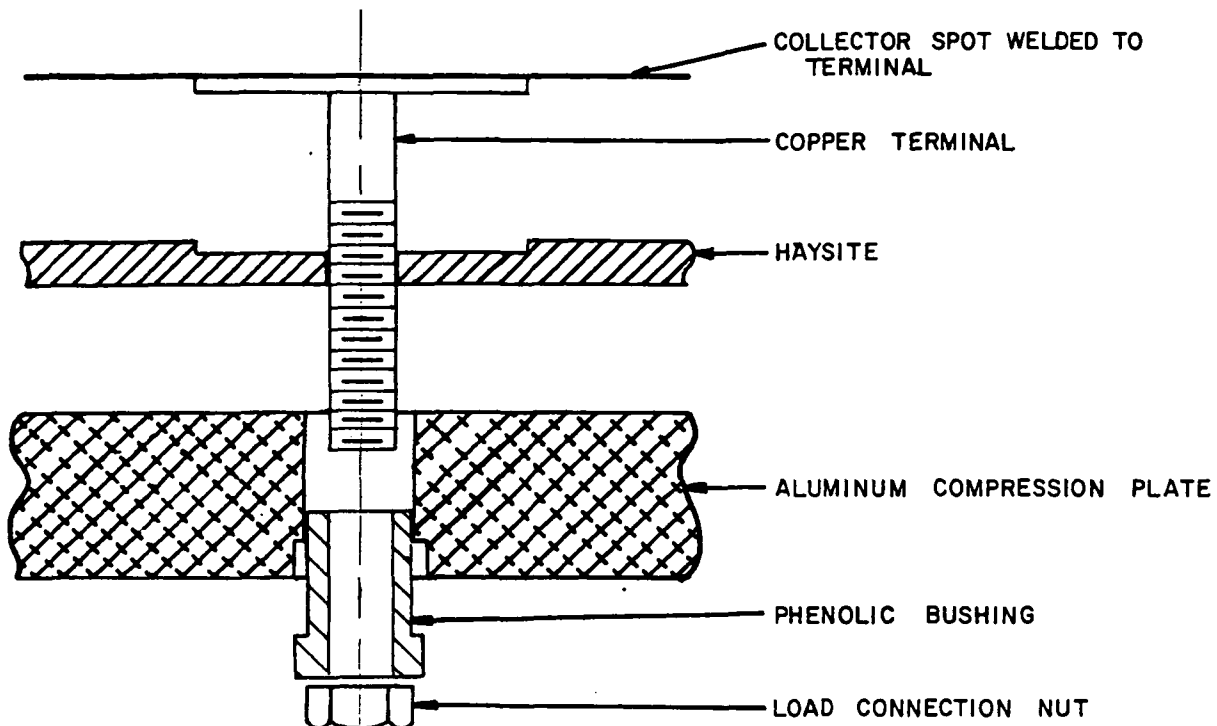
* ERC proprietary matrix

Thicker bipolar end plates (~ 0.53 cm thick compared to ~ 0.43 cm thick plates) are proposed to provide a wider seal area between the manifolds and the stack. This should reduce or eliminate the leakage sometimes encountered in this area.

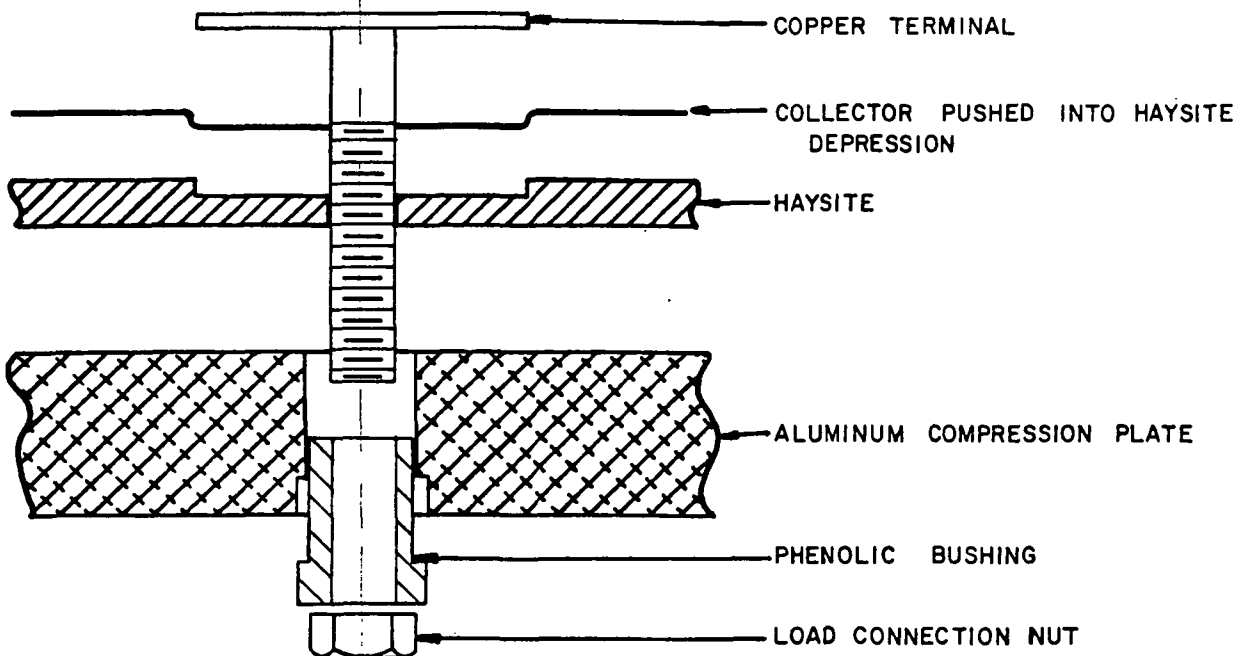
High resistances between the end bipolar plates and the terminal studs were measured on 1200 cm^2 , 2kW stacks. These resistances increased with operating time. In these stacks, the copper terminal stud was spot-welded to a copper sheet current collector (Figure 1-a). The welds broke during tightening of the nut to connect the load. The terminal design (shown in Figure 1-b) involves a depression machined in the haysite insulator. As the load nut is tightened, the "copper terminal" presses the current collector into the depression and the contact between the terminal and the collector is increased. Since there are no welds, twisting the terminal bolt does not cause any damage. This design for terminals/current collectors is being incorporated in stack 559.

Stack Mechanics - Load deflection characteristics of a bipolar plate material and a dry electrode-matrix composite were measured. An initial load of 138 kPa produced a deflection of approximately 10 percent of the original thickness of the electrode-matrix composite. The modulus of elasticity of the bipolar plate sample was 11×10^5 kPa and the modulus for the electrode-matrix composite was 11.3×10^3 kPa for loads between 170 and 1400 kPa at room temperature.

The measured characteristics were used in an analysis to determine the effective mechanical properties of the stack in terms of the component properties and geometry. The analysis showed that when the bipolar plate and electrode-matrix elements are combined, as in a stack, the effective modulus based on total area is about 8300 kPa. The analysis predicts that 99 percent of stack compression occurs in the electrode-matrix layers and only 1 percent occurs in the bipolar plate. The analysis also predicts that if the stack compressive load is applied by bolts, thermal expansion of the restrained stack will be 2 percent of the unrestrained stack thermal expansion.



a. PREVIOUS ARRANGEMENT



b. IMPROVED ARRANGEMENT

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FIGURE 1. IMPROVED DESIGN FOR TERMINALS/CURRENT COLLECTORS
ELIMINATES WELDED JOINT

1.3 Full Scale Module Designs

Cost Analysis

The cost estimate for the repeating stack components of the benchmark design has been completed. The benchmark will be the basis of the comparison for alternative designs and processes. The cost estimates are based on manufacturing 16,700 fuel cell stacks per year. The equipment and processes used for establishing the benchmark reflect large scale production and is devoid of laboratory equipment. NASA's (Jet Propulsion Lab. California) Interim Price Guide Line (IPEG) model (which is a subset of NASA's Solar Array Manufacturing Industry Costing Standards - SAMICS) has been used for this study.

The word "costing" requires additional explanation. The IPEG model automatically provides for a 20% return on assets. Thus the costs shown in this study include this profit plus other standard factors which are a part of the cost model. The IPEG cost model has been purposely selected for this cost estimate, because the overhead factors, have been standardized. Consequently, many of the burden factors which may be unique to a specific contractor have been eliminated. The simple equations and coefficients of the IPEG model are shown in Appendix A. Page 7C of this appendix shows assumptions used for developing overhead costs. The second line from the bottom indicates a 20% return on equity capital (profit). It is because of this inclusion of a profit that the last line of Page 7C reads: "This system of equations is solved for price" and not cost.

Benchmark definition - Area of a single fuel cell : 1200 cm²

Number of cells per stack: 300

Repeating components:

Bipolar Plate

Cathode

Anode

Matrix

Cooling Plate - 1 for 5 cells

The description of the process is in the First Quarterly Report.

As indicated in Appendix A, the IPEG costing model has five major cost components. The distribution of these components is shown in Figure 2. The support for this graph is given in Table I. It is obvious that material is the dominant cost component and the major portion of this component is the platinum catalyst. The platinum costs used for this study were those prevailing on March 26, 1980 or \$440.12 per troy ounce. Further breakdowns of the equipment and labor estimates are illustrated in Figures 3 and 4 respectively. Because some materials and processes are of a proprietary nature, no further breakdown of the material cost components are given, however, the totals include the cost of the proprietary material cost components. Where practical, modern, continuous high production processes have been used for developing the cost estimates. Patent disclosures for assembling the fuel cells and their enclosure were written and will be submitted to NASA.

One manufacturing concept for continually assembling fuel cells is depicted in Figure 5. This is a wet assembly where the phosphoric acid is roller-coated onto the matrix. Since the cutter operates intermittently, it is necessary to separate the coating and cutting operation by a loop pit which allows the coating process to proceed continually. Thus no bead is formed along the coating roller as would be the case in an intermittent operation. A stacking Table at the end of the line is indexed downward with each fuel cell. An operator (not shown) manually feeds bipolar plates on to the stacking table prior to the descent of the cutter.

FIGURE 2

PHOSPHORIC ACID FUEL CELL
REPEATING COMPONENTS

COST DISTRIBUTION — IPEG MODEL

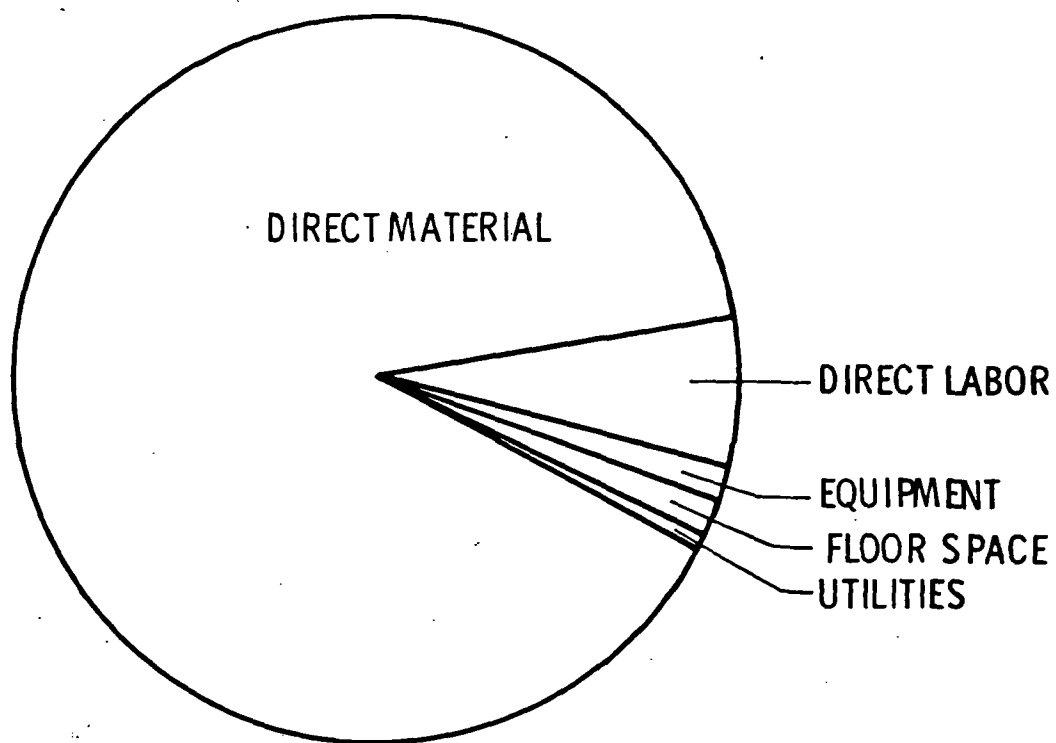


TABLE I

PHOSPHORIC ACID FUEL CELL REPEATING COMPONENTS

JPL IPEG COST MODEL

COST ITEM	IPEG FACTOR	ESTIMATE OF COST ITEM	IPEC COST (MILLION \$/YR)	\$/KW
EQUIPMENT	.489	\$ 5,064,000	2.480	4.96
FLOOR SPACE	96.9	22,125 SQ. FT.	2.140	4.28
DIRECT LABOR	2.133	\$4,700,000/YR	9.97	19.94
DIRECT MATERIAL	1.255	\$111,400,000/YR	139.3	278.60
UTILITIES	1.25	\$330,000/YR	.4	.80
TOTALS			154.29	308.6

FIGURE 3

PHOSPHORIC ACID FUEL CELL EQUIPMENT COST ESTIMATES

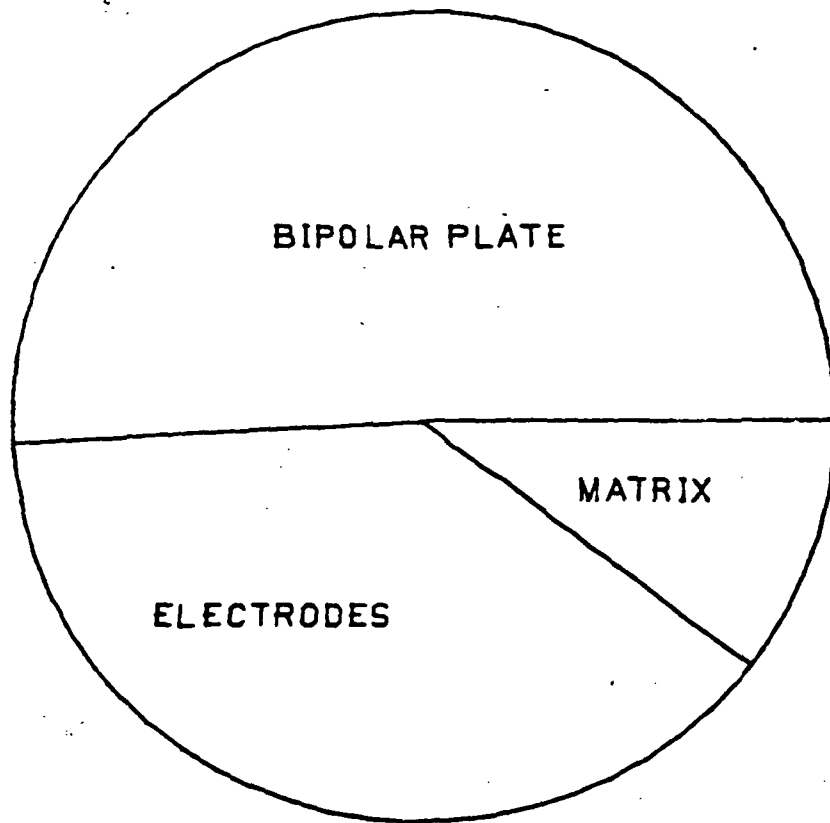
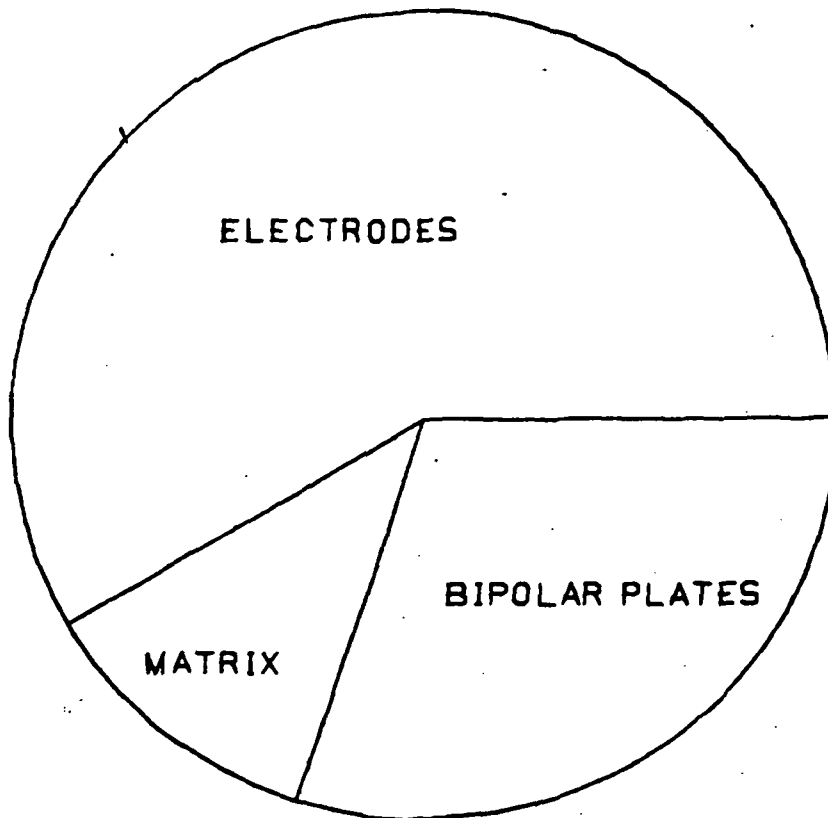


FIGURE 4

PHOSPHORIC ACID FUEL CELL LABOR COST ESTIMATES



ASSEMBLY OF REPEATING COMPONENTS, PHOSPHORIC ACID FUEL CELL

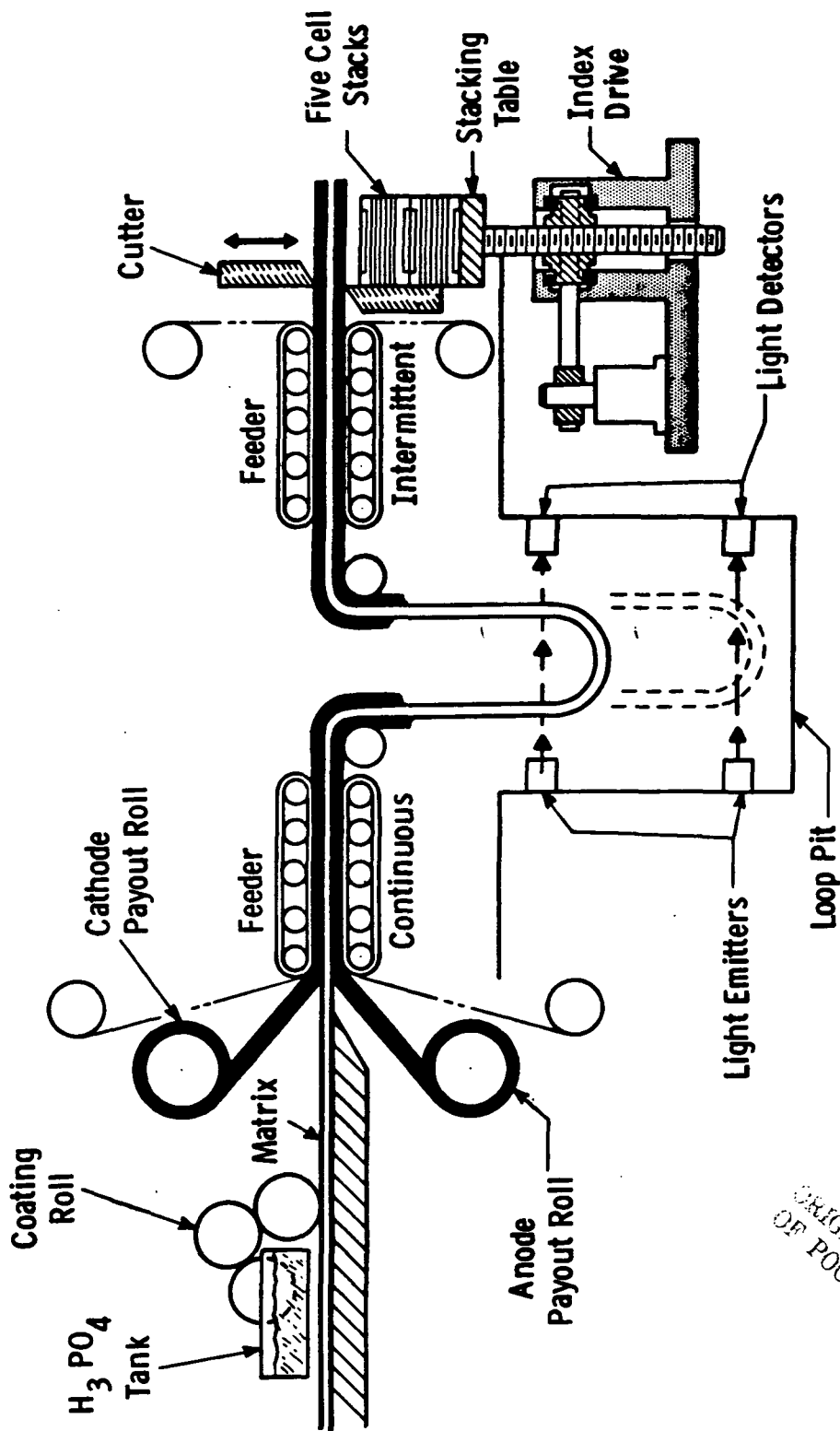


FIGURE 5

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TASK 2: STACK FABRICATION

2.2 Simulated Stack Fabrication

During this quarter, fabrication of the second MK-2 simulated stack (No. 558) was completed and fabrication of the third simulated stack (No. 560) was started. A further description of these stacks follows:

Stack 558

The second MK-2 design simulated (5-cell) stack, No. 558, was assembled with rolled anodes ($\sim 0.3 \text{ mg Pt/cm}^2$) and cathodes ($\sim 0.5 \text{ mg Pt/cm}^2$), Kynol matrices and Kynol shims. All of these components were wetted with $\sim 100\% \text{ H}_3\text{PO}_4$ during assembly, which took place in a dry room. The amount of acid for wetting the cell components was 47 cc/cell (38cc in the matrix and electrodes and 9 cc in the shims). After assembly, the stack was heated and the acid in the components was allowed to equilibrate overnight with no compression other than the weight of the end plates. The following day, 60 psi nominal compression was applied to the stack. The stack was then readied for pretesting.

Stack 560

Fabrication of components for a third MK-2 simulated stack (No. 560) is now in progress.

Graphite-resin blanks were molded and machined for 5 bipolar plates and 2 of each of the end plates, totaling 9 plates. These plates are now being post-cured. Fabrication of the other components is also in progress. Construction of stack 560 will be similar to Stack 558 with these modifications:

1. Stack 560 will contain Mat-1 matrices instead of Kynol.
2. Electrolyte filling Scheme II will be used.*
3. A means to prevent matrix swelling into the acid channel *

* This scheme was described in a patent disclosure submitted separately to NASA.

Fabrication of Stack 560 is anticipated to be completed in mid-July.

2.3 Short Stack Fabrication

During this quarter, fabrication of components for three short stacks (23 cell, 1200 cm^2) was initiated. The main features of these stacks are discussed in the following subsections and are summarized in Table II.

The stacks will utilize the modified cooling channel configuration and will incorporate rolled electrodes with catalyst loadings of ~ 0.3 and $\sim 0.5 \text{ mg/cm}^2$ on the anode and cathode, respectively.

Stack 559

Stack 559 is a DIGAS Cooled, MK-1, short stack with Kynol matrices. The stack will be assembled with prewet components with no shims, using the electrolyte filling Scheme II. A means to prevent matrix swelling into the acid channels will be incorporated.

All the components of Stack 559 have been fabricated with the exception of the cooling plate subassemblies. Difficulties have been encountered in obtaining crack free plates due to bowing caused by residual stresses. Cracks occurred in some of these plates during the machining operation and in others during efforts to straighten them prior to cementing the cooling plate halves together.

The target date for stack assembly is 7/15/80

Stack 561

Stack 561, a MK-1 design stack, will also incorporate rolled electrodes with the same catalyst loadings as Stack 559 but will have Mat-1 matrices. The aforementioned modifications in design and procedures (acid fill scheme, sealing and current collection terminals) are to be incorporated in this stack.

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TABLE II. SPECIFICATIONS FOR 1200 cm² SHORT STACKS

STACK	COOLING SCHEME	MATRIX	BIPOLAR PLATE DESIGN	TARGET ASSEMBLY DATE
559	DIGAS	Kynol	MK-1	7/15/80
561	DIGAS	Mat-1	MK-1	8/20/80
562	Separate	Mat-1	MK-2	9/10/80

Blank cooling half plates have been molded and are to be machined. The other components for the stack are being fabricated. The target date for assembly is August 20, 1980.

Stack 562

Fabrication of components for Stack 562, a MK-2 stack, was initiated. Stack 562 will have the same electrodes as 559 and 561 and will have Mat-1 matrices. Since it is a MK-2 design, all of the bipolar plates as well as the cooling half plates for this stack will be machined. Blank plates are now being molded for machining and will be machined before post-curing. The target date for the assembly of this stack is September 10, 1980.

TASK 3: STACK TESTING

3.1 OS/IES Simulation Facility

In order to check out the Waugh three gas blending system within the warranty period covering 6 months from the date of delivery, we installed the unit as per Waugh instructions. We experienced difficulties obtaining gas flows on all three channels and called Waugh for assistance. The Waugh Controls Corp. sent representatives to inspect their equipment and determine the reasons for the malfunction. Following diagnostics and repair by Waugh, we were able to check the lower range of each channel using the proper gas for each with our precision rotometers. Also, with CO₂ supplied to all three channels, we confirmed that the unit could stably control a desired 3 gas mixture. For future operation we recommend the addition of 3 high range precision rotometers which can be used to periodically check the calibration of this unit.

3.2 Simulated Stack Testing

Pre-test Procedures

Stack pre-testing procedures were reviewed during this quarter and a revised pre-test plan was formulated. These revisions in pre-test procedures reflect the modifications in acid fill procedures now employed in these stacks. Limits at each test station have been incorporated in these procedures for diagnostic decisions.

Stack 558

The objectives of Stack 558 testing were to:

- establish the performance of the MK-2 design
- test wet assembly procedures on this design
- test acid filling and replenishment in the horizontal position
- evaluate the manifold seal design.

During pre-tests at 100°C, the internal stack resistance had stabilized at 1.76 mΩ per cell after several days and open circuit voltage (OCV) was ~0.75V/cell. However, transient OCVs (H₂ on/Air off) were unstable and declined within a minute for some of the cells. A manifold leak test indicated negligible external leak. After further acid additions, higher OCVs (~0.82 V/cell) were recorded and the transient OCV was more stable.

Measurements made on this stack included:

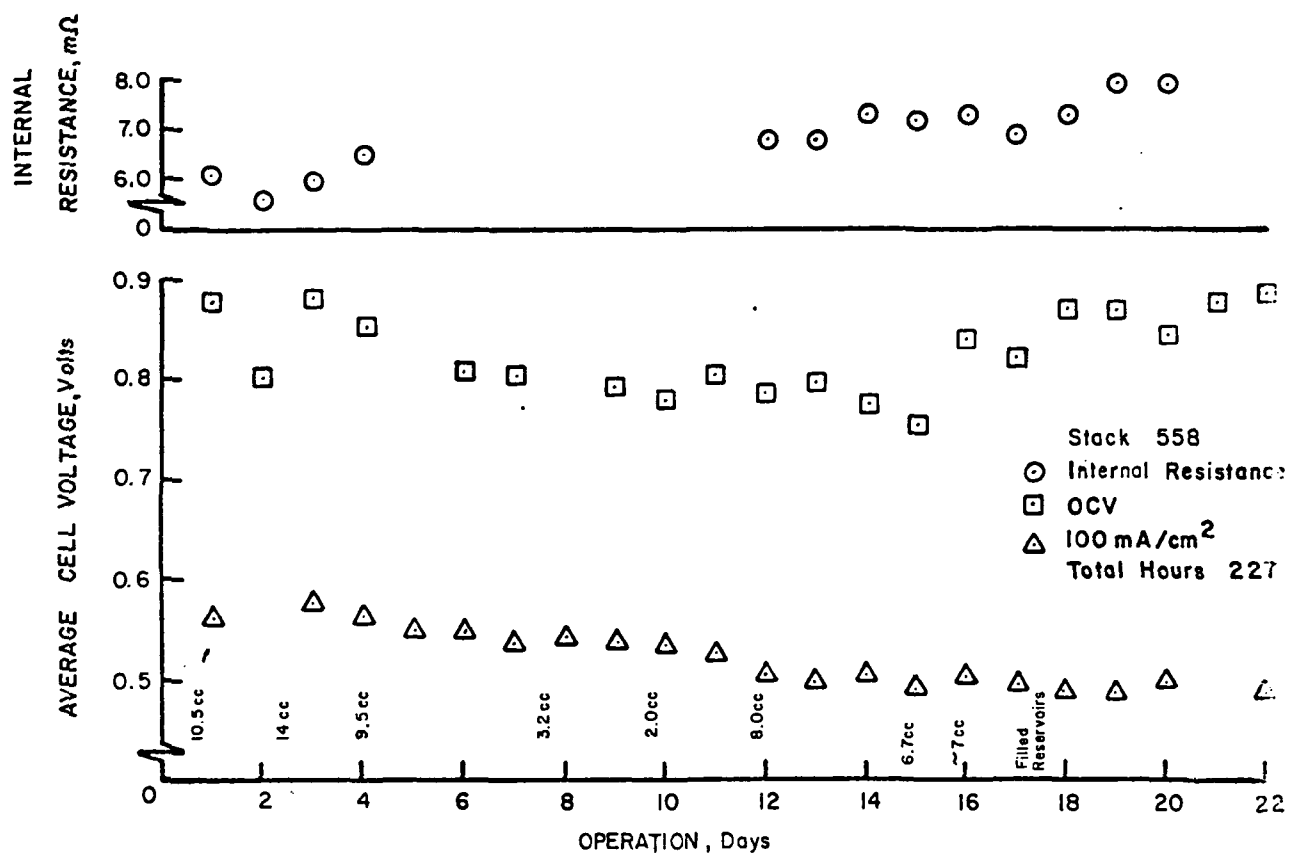
1. OCV and stack voltage at 100 mA/cm² and 177°C.
2. Polarization data for the stack.
3. The effect on stack performance of air flow rates in the range of 2 to 5 stoich and of hydrogen utilization in the range of 50 to 80%.

The performance history of Stack 558 is shown in Figure 6. Initially the average cell voltage was ~0.57V at 100 mA/cm² and the OCV was ~0.88V. However, both OCV and on-load performance decreased with time. Subsequent acid additions improved stack OCV and the transient OCV's were more stable but improvement in on-load performance was not clear.

A comparison of polarization data for Stacks 557 and 558 appears in Figure 7. Data was taken at about the same time in the life of each stack (i.e., on the third day of testing). The performance of stack 558 was ~80mV/cell higher at 150 mA/cm². This improvement appears to be due to the fact that acid was added to the matrix of 558 prior to assembly (wet assembly).

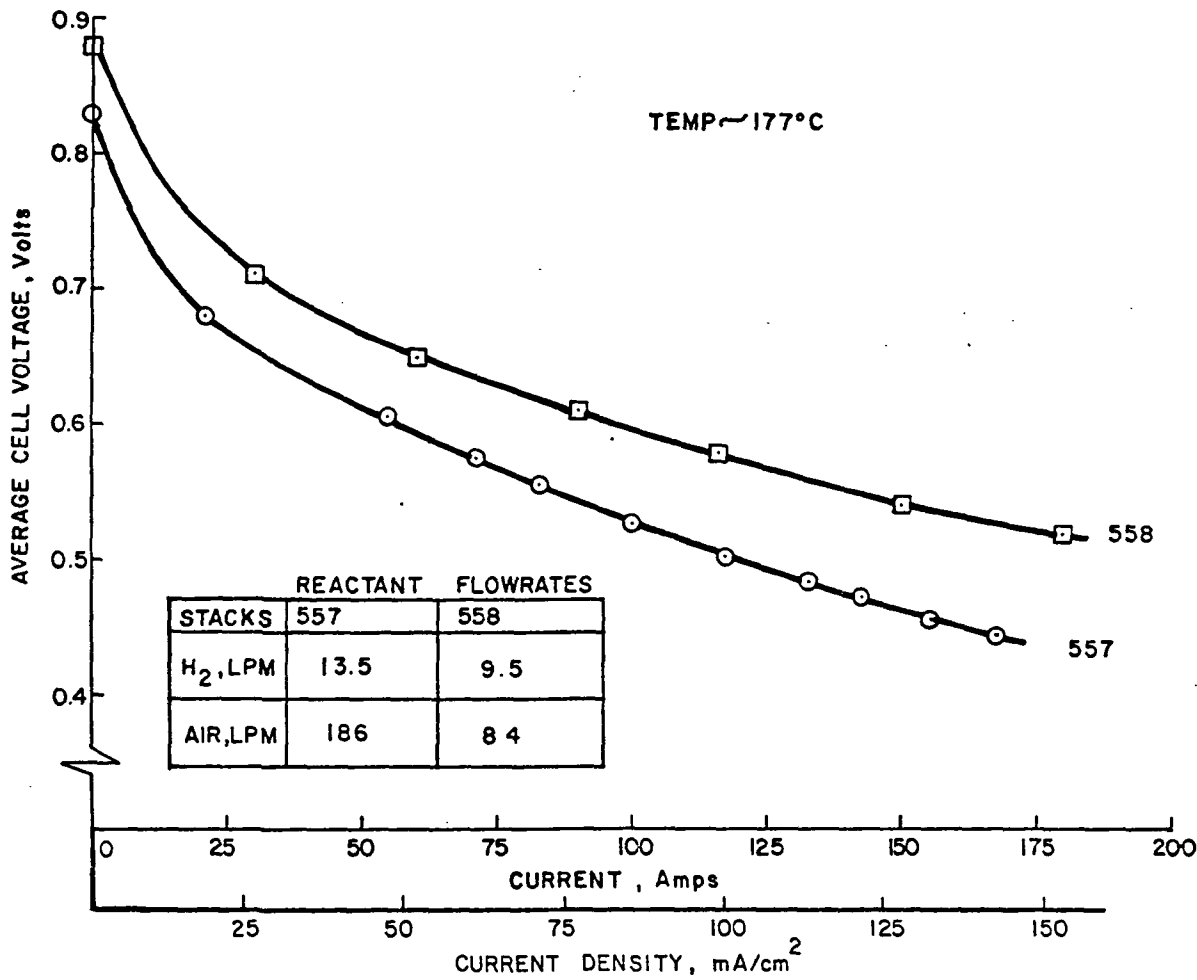
As indicated on Figure 6, more acid was added to the stack through external fill tubes and the reservoirs using Scheme I*, as planned but OCV and performance declined in patterns, similar to those of other stacks built under this program. The marked improvement in OCV which occurred on operating days 16 and 18 combined with the post test analysis

* Described in patent disclosure submitted separately to NASA



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FIGURE 6 LIFEGRAPH OF STACK 553



D1231R

FIGURE 7
AIR POLARIZATION OF STACKS 557 and 558

described in the next paragraph, indicate that a deficiency of acid was at least partially responsible for the low average values obtained. The apparent deficiency of acid in at least some cells was due to a combination of factors including:

1. A concern that the electrodes might be flooded.
2. Unavailability of an unambiguous method for discriminating between electrode flooding and acid deficiency.
3. Scheme I provides no positive indication that all cells are receiving acid.
4. The procedures for this stack did not provide for acid addition in the test stand, hence acid addition was a time consuming process.

In a last effort to recover good performance, on the 17th day the acid drains were closed to fill the acid reservoirs. Transient OCV and operating OCV's measurements indicated that this successfully filled the matrices but the performance of cell 5 was so poor (~ 0.4 volts at 100 mA/cm^2) that the stack was terminated. Post-test analysis of the Stack indicated that the matrices and electrodes were drier than typical cells. Cell 5 was the driest (in terms of electrodes) and had the worst on-load performance of any cell throughout the life of the stack. Cell 3 was the wettest and exhibited the best on-load performance.

The acid addition method used in stack 558 (Scheme I) does not provide a positive indication that electrolyte is being supplied to each cell. Scheme II does provide this positive indication and our plans call for its use in future stacks.

The effect of varying air and H_2 flow rates on the on-load performance of Stack 558 is shown in Table III. The results indicate that the stack's performance becomes practically insensitive to H_2 utilization below $\sim 74\%$ and air flow rate above 2.3 stoich.

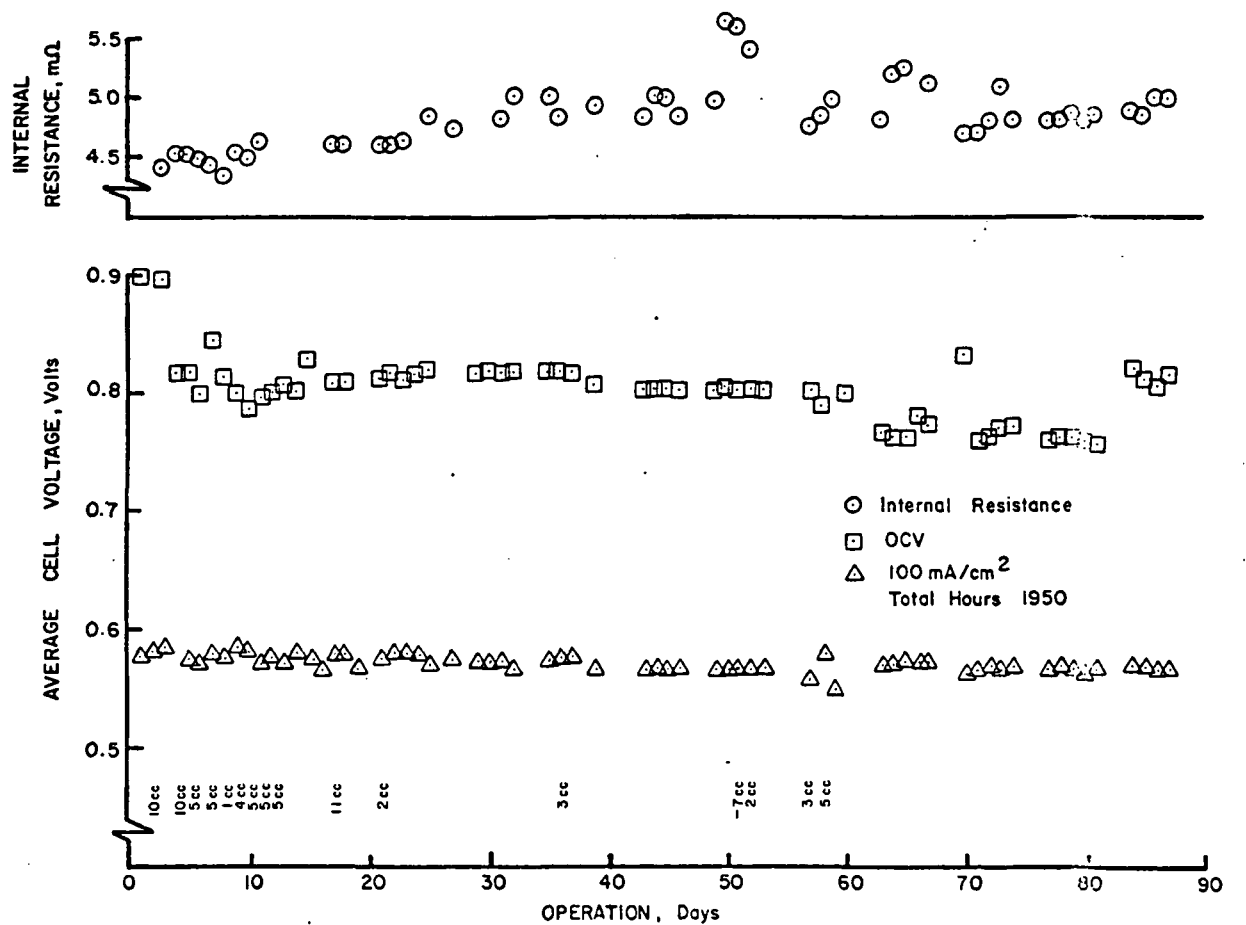
Electrolyte Filling

As indicated in the Second Quarterly Report, a 350 cm^2 3-cell stack was built to test the electrolyte filling Scheme II. The stack accumulated

TABLE III EFFECT OF AIR FLOW RATE AND H₂ UTILIZATION
ON THE PERFORMANCE OF STACK 558

STOICH AIR	H ₂ UTILIZATION, %	AVG. CELL VOLTAGE, V @ 100mA/cm ²
2.3	74	0.538
3.9	74	0.540
6.3	74	0.544
6.0	80	0.528
6.0	50	0.538

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FIGURE 8 LIFEGRAPH OF STACK C

a total of ~2000 hours with a stable performance level of 0.57 V/cell at 100 mA/cm². The initial acid inventory in the stack was augmented during the first 400 hours of operation. After these adjustments, only negligible acid additions were made. The performance of Stack C was very stable throughout its operation (Figure 8). The only dip in on-load performance, occurring around the 58th day of operation, was caused by a reduction of air supply due to a cracked air inlet manifold. After the manifold was repaired, performance at the previous level was re-established. The successful operation of Stack C demonstrated that Scheme (II) is a viable means for both initial electrolyte filling and replenishment of acid inventory.

Post-test analysis showed the components were uniformly wet, blockage of the process channels was negligible, and both current collectors were dry and in good condition. This acid fill scheme will be used in Stack 559.

Thermal Behavior of Stack Hardware

To determine the extent of stack deformation with temperature, a preliminary calculation was performed on an 80 cell stack and described in the Second Quarterly Report. In this calculation, only the major components (i.e., bipolar plates, aluminum compression plates, Teflon insulators, compressions pads, bars and rods) were included. These comprised more than 92% of the stack height; the more deformable cell components such as matrices, electrodes and shims were not included. To verify the results of this calculation, an 80 cell stack with Mat-1 matrices was measured. Under the nominal stack compression of 60 psi at two different temperatures, 25 and 74°C, a net shrinkage of the stack was found. Since the major components expand with temperature, the more deformable bodies must have shrunk. This is an important design aspect for a long stack (~300 cells) with respect to sealing, manifolding, stack compression, etc. Consequently further work on the detailed study of cell deformable bodies is being planned.

3.3 Short Stacks.

2 kW Stack Testing

Pre-testing of Stack 559 (a MK-1 design, 23-cell, DIGAS stack) is planned for mid July. The test plan for this stack includes establishing baseline performance at 150 mA/cm^2 and 177°C as well as determining experimentally the air flow rate ratio between the process air (cells) and cooling air (DIGAS plates). A scheme has been devised using pressure drop measurements across the air side of the stack for flow split determination.

The stack will be operated in three modes, and pressure drop data versus air flow rate will be obtained. The three modes of operation are:

1. Through both cells and cooling plates
2. Through cells only, by blocking cooling plates
3. Through cooling plates only, by blocking cells.

Mode 1 simulates normal stack operation. It will provide the pressure drop data for various total flow rates through the stack. By matching the pressure drop across the cells (Mode 2) and stack (Mode 1) the flow through the cells will be the same. The difference between total stack flow and cell flow should be equal to the cooling plate flow at the same pressure drop and can be cross checked by Mode 3 results.

3.4 Test Stand Design and Construction

3.4.1 2 kW Test Facility

The basic design of the air flow loop and selection of major equipment was completed and orders were placed for all major components. Some components have been received and assembled and others are in various stages of assembly and/or installation.

Air Circulation loop

Component arrangement and design of the air circulation loop was finalized and all parts were ordered. A vertical arrangement was selected, as indicated pictorially in Figure 9, , to provide easy access to all components and minimize the required floor space. Approximate loop dimensions are 5 m long x 2.4 m high x 1 m wide. The piping is 7.6 cm O.D. and made of Type 304 stainless steel 0.15 cm thick. The fittings (tees and elbows) are of the type used in pneumatic conveying and have minimal pressure drop. Details of the blower section side and blower discharge side are given in Figures 10 and 11 respectively. Table IV is the legend for Figures 10 and 11.

The air preheater was assembled and is shown in Figure 12. Three heating elements are mounted with compression fittings into a piece of 7.6 cm diameter pipe. In order to provide a better coverage of the pipe cross section, the axis of each element is positioned 120° with respect to the others. Each heating element is individually powered from a variable transformer.

Emergency Shutdown System

A schematic of the 2 kW test loop emergency shutdown system, instrumentation, and controls is shown in Figure 13. The proposed solenoid safety valves for the hydrogen feed and mixed anode gas lines were replaced with pneumatically operated ball valves, because the manufacturers would not guarantee solenoid valves to be hydrogen tight in the sizes required. The ball valves are slightly more expensive but are hydrogen

MK-1 STACK
 AIR CIRCULATION LOOP
 PICTORIAL VIEW OF 2kW
 TEST STATION

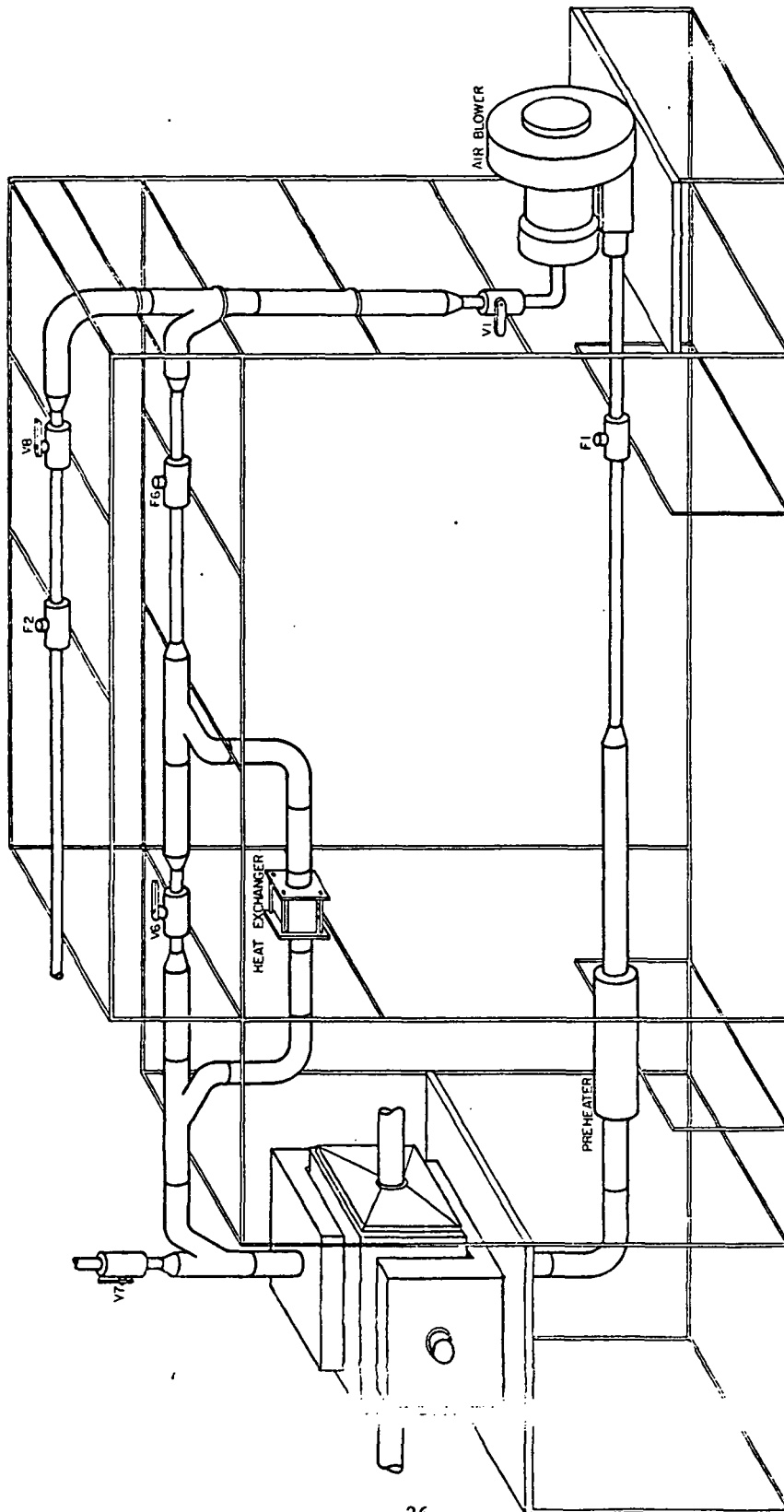
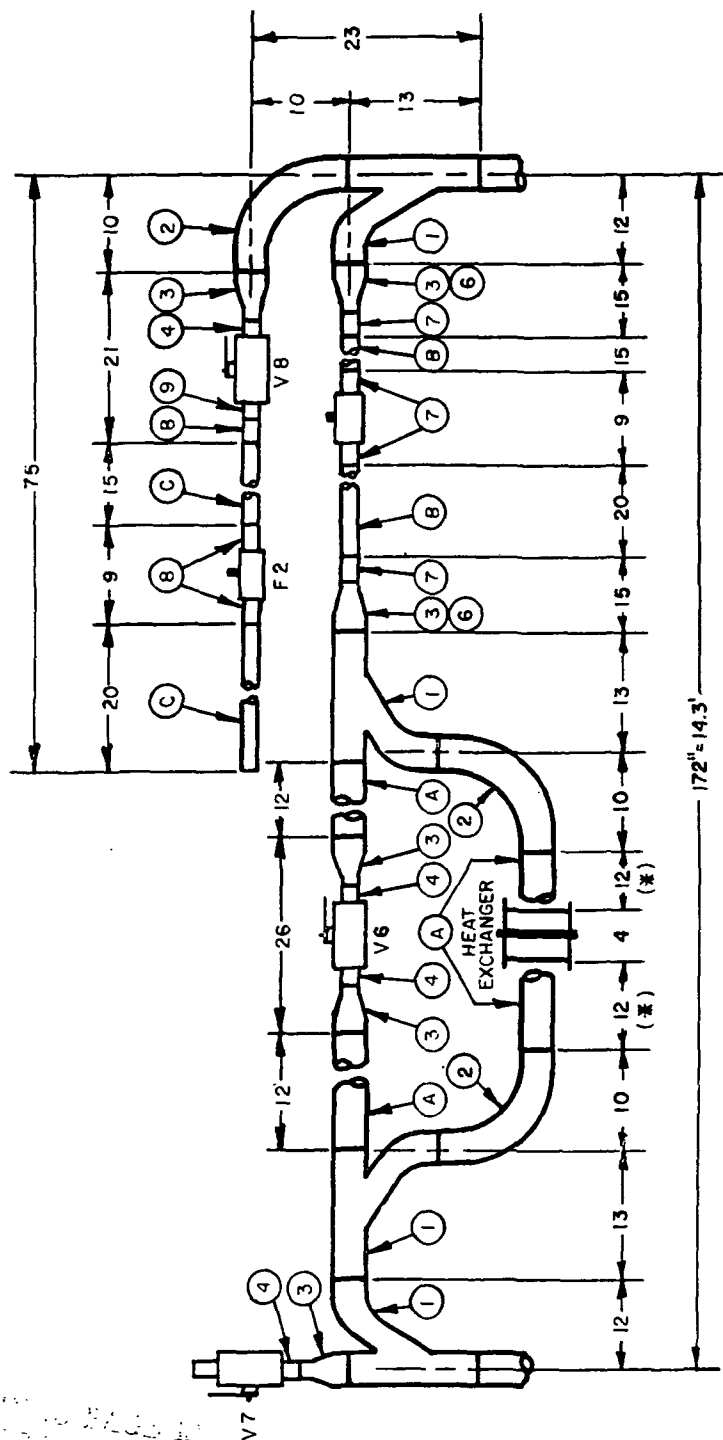


Figure 9.

FIGURE 10



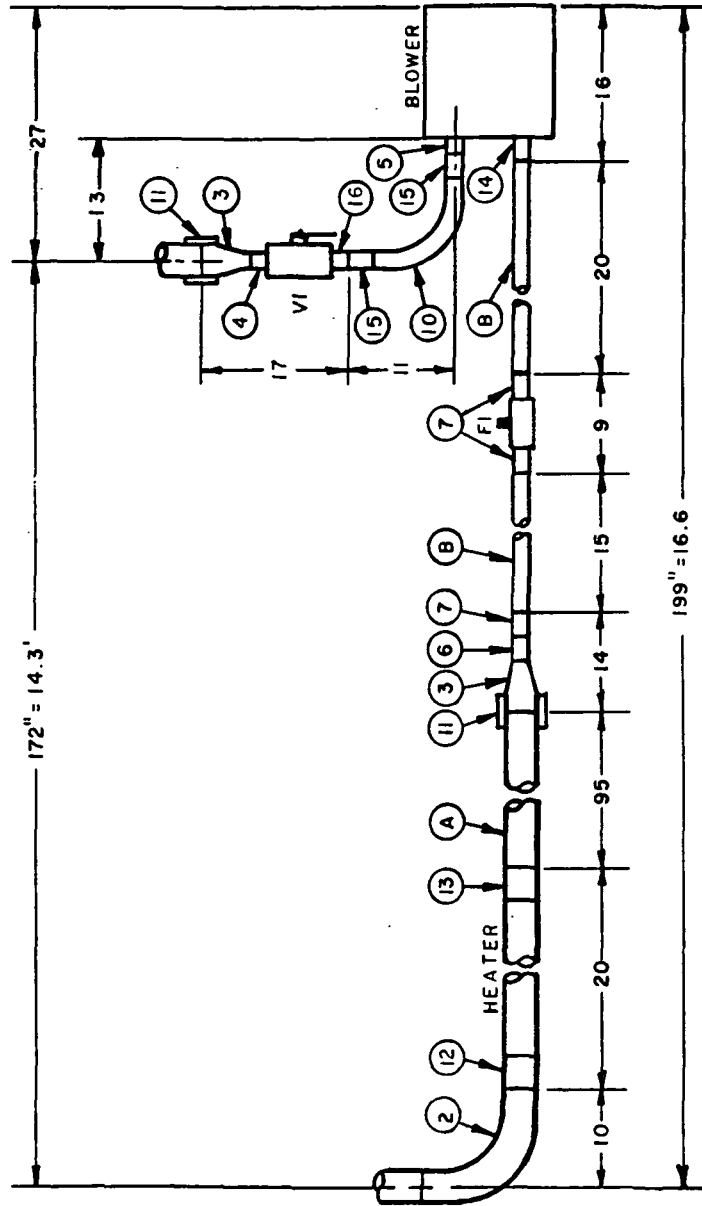
ALL DIMENSIONS ROUNDED TO THE NEXT INCH
* 12 INCHES PROVIDED FOR HEAT EXCHANGER MANIFOLDS

- ☐ A 3" x .060 TUBE
☐ B 1 1/2 x .060 TUBE
☐ C 1 1/4 x .060 TUBE

D1172

FIGURE 11

MK-1 STACK 2 kW TEST STATION
AIR CIRCULATION LOOP
BLOWER DISCHARGE SIDE



NOTES

→ ALL DIMENSIONS ROUNDED TO NEXT INCH

- (A) 3" x .060 TUBE
- (B) 1 1/2" x .060 TUBE

D1171

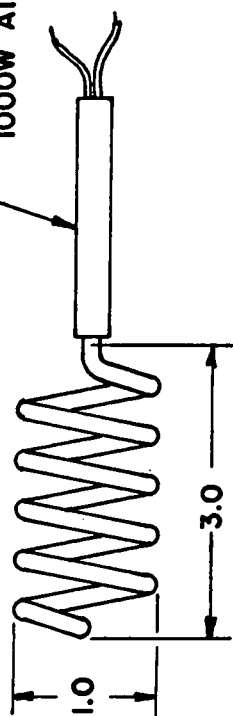
TABLE IV

Legend to Figures 10 and 11

1. Standard 90° tee
3 in. diam. tube
2. Standard radius 90° elbow
3 in. diam. tube
3. Reducing coupling
3 to 2-1/8 in. diam. tube
4. Pipe to tube adapter
2 in. MNPT to 2-1/8 diam. tube
5. Reducing pipe nipple
2 in. MNPT to 1-1/2 MNPT
6. Pipe to tube adapter
2-1/8 diam. tube to 1-1/2 MNPT
7. Pipe to tube adapter
1-1/2 FNPT to 1-1/2 diam. tube
8. Pipe to tube adapter
1-1/4 FNPT to 1-1/4 in. diam. tube
9. Reducing pipe nipple
2 in. MNPT to 1-1/4 in. MNPT
10. Standard radius 90° elbow
2-1/2 in. diam. tube
11. Compression coupling
3 in. diam. tube
12. Pipe to tube adapter
3 FNPT to 3 in. diam. tube
13. Pipe to tube adapter
3 FNPT to 3 in. diam. tube
14. Pipe to tube adapter
1-1/2 MNPT to 1-1/2 in. diam. tube
15. Pipe to tube adapter
2 FNPT TO 2-1/2 in. diam. tube
16. Pipe nipple
2 MNPT

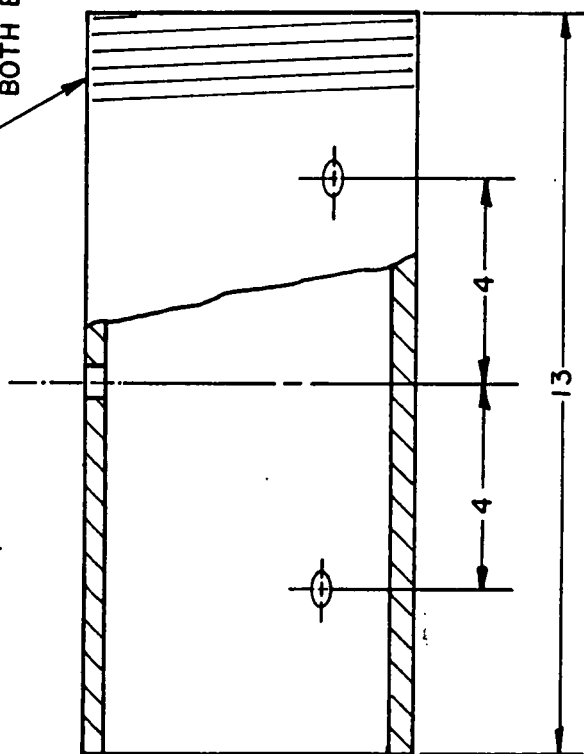
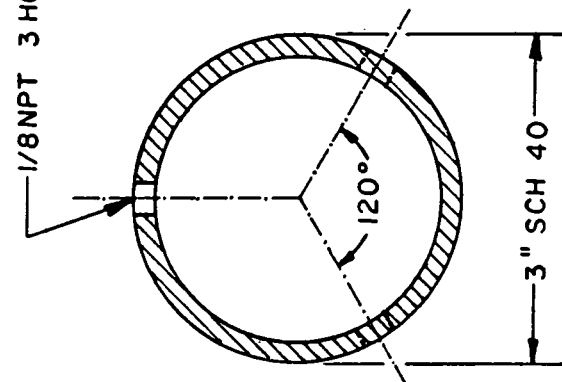
**MK-1 STACK 2kW TEST STATION
AIR PREHEATER**

HEATING ELEMENT
1000W AT 110V



1/8NPT 3 HOLES

3" NPT
BOTH ENDS



ALL DIMENSIONS IN INCHES

FIGURE 12

D1236

**MK-1 STACK
2 kW TEST STATION
(EMERGENCY SHUT-DOWN
CIRCUIT SHOWN)**

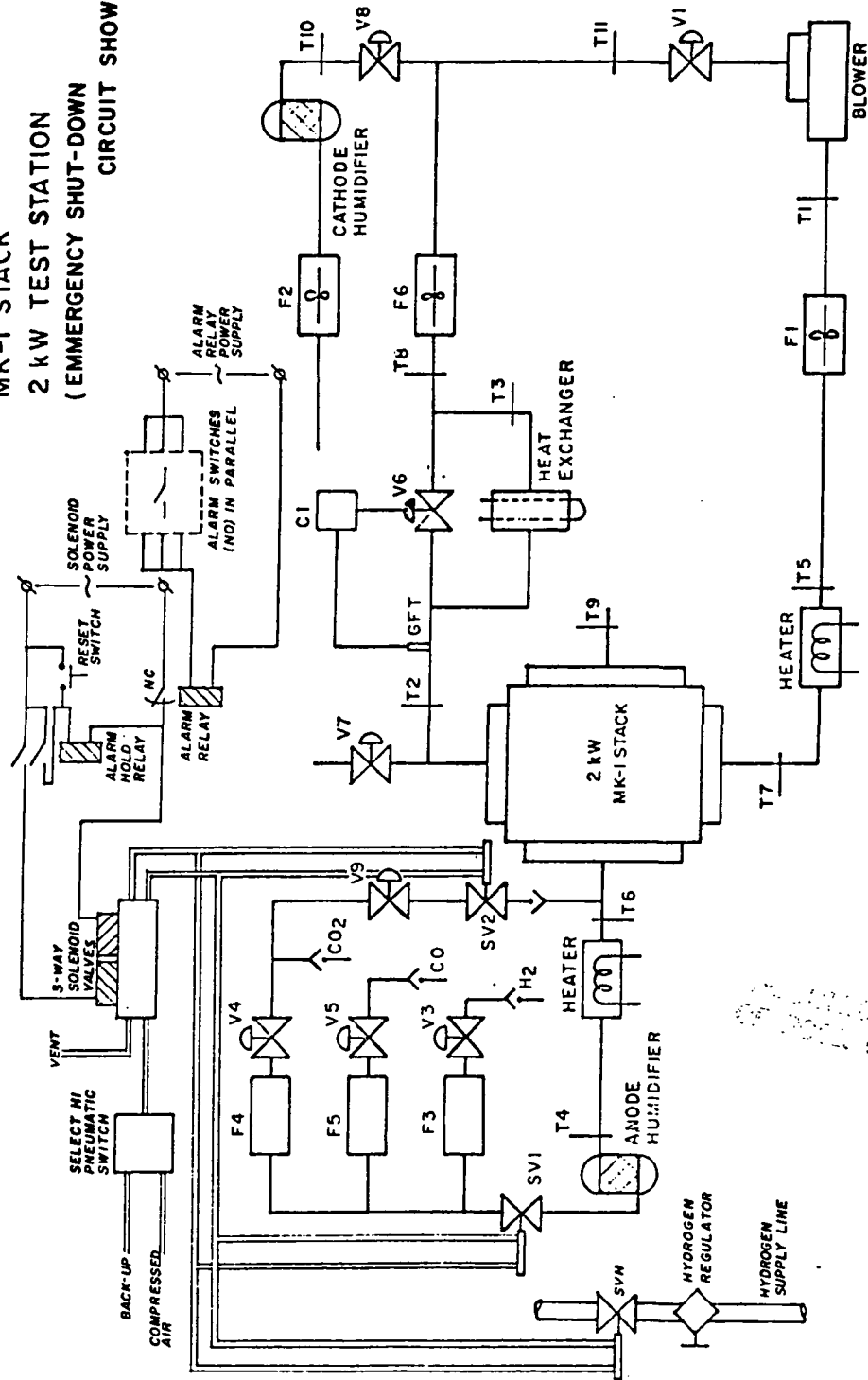


FIGURE 13

D1235

tight. Two 3-way solenoid valves will be used to convert the electric signal from alarm switches into a pneumatic signal to actuate the valves.

A back-up line from a high pressure cylinder will activate the pneumatic pressure switch in case of a drop in line pressure below the safe operating condition (~ 550 kPa).

Data Acquisition System

During this quarter, final selection of a computer driven Data Acquisition System was made. The system consists of the following Hewlett Packard components;

- Automatic Data Acquisition Control - HP 3054A unit
- Interfacing System - HP 85A computer
- Printer - HP 2631B

This system is comparable in price to the previously proposed system and has the following advantages;

1. Offers greater programming flexibility because it is keyboard programmable.
2. It is capable of data reduction.
3. It gives data printout in the desired format.
4. If more than one stack is to be monitored simultaneously, this system can give a printout for each stack.

Delivery of all components is promised during the next quarter.

Miscellaneous Components

A Bacharach Instruments oxygen analyzer was selected and ordered and should be delivered in the next quarter. The selected analyzer has an accuracy of 0.25% but requires somewhat more sample conditioning than the alternate which had an accuracy of 2%.

Flanges for the heat exchanger shown in Figure 13 were assembled for installation in the air loop.

The design and assembly of the electrical resistor load bank was completed. Each resistor is connected into the circuit through a heavy duty contactor. Thus the load can be remotely controlled. The cost of this design is lower than the equivalent carbon pile rheostat. Also the load bank is compatible with automatic testing and control.

TASK 4: FUEL CONDITIONER DEVELOPMENT

4.1 Fuel and Water Definitions

The definitions for fuel in Section 4.1.1 of the Second Quarterly Report and for water in Table VII of that report essentially completed this task. The fuel definition is being used as the basis for Task 4.2, Operational Requirements, and the water definition provides the basis for specification and assessment of water treating equipment options under Task 4.4.2, Water Conditioning System Development.

4.2 Operational Requirements Definition

As indicated in the Second Quarterly Report, work has begun on revising the state point diagram developed in Phase I. New reformer concepts, the fuel definition, developed under subtask 4.1.1, and a requirement for part load as well as full load stream flows formed the basis for this effort. During April, an analysis of the reformer and shift converter was started to define conditions of temperature, pressure and flow at full and at one-third power. The analysis assumes that two 60 kWDC reformer modules provide hydrogen to four 30 kWDC fuel cell stacks which generate the 120 kWDC required by the OS/IES design load. Reformer and shift converter performance were based on the average gas composition on page 29 of the Second Quarterly Report.

Discussions with Energy Research Corporation indicated that after reforming, a combination of a high temperature shift converter in series with a low temperature shift converter might be attractive. The following two cases showed that it would be less costly and just as effective to use a heat exchanger and a single low temperature shift converter.

In case I it was assumed that the reformer effluent entered a heat exchanger at 815°C and was cooled to 230°C. The sensible heat load for this energy transfer per mole of feed was 12,540 kCAL. The heat of reaction in the shift converter was then 2950 kCAL to produce less than 1 percent CO at full flow.

In case II, the heat transferred per mole of feed from a high temperature shift converter operating between 815°C and 360°C was 12,015 kCAL (sensible plus heat of reaction). The heat load on the low temperature shift (360°C - 225°C) was 3580 kCAL (also producing less than 1 percent CO). The high temperature shift converter was rather ineffective due to high CO in equilibrium at the 360°C exit temperature. It really behaved as a catalyst coated heat exchanger.

Since the heat loads on the respective components are about the same in the two cases, the total heat transfer areas will be nearly the same. Since a satisfactory reduction in CO concentration can be obtained with one shift converter (case I) instead of the two (case II), economics and maintainability favored case I which makes better use of available catalyst area.

Initial reformer heat balance calculations indicated that an upper limit on reforming gas temperature of 715°C leaves sufficient unreformed methane to allow reformer operation on spent fuel (see Figure 14). The exact amount of methane required is yet to be determined from combustion gas temperature calculations, heat transfer considerations, and selection of co-current or counter current reformer configuration.

As part of the effort necessary to decide which reformer configuration is best, an energy and mass balance calculation for a co-current reformer was made. For the assumed conditions (e.g., 1200°C combustion temperature, 620°C preheat of combustion air and fuel, and 535°C preheat of the steam/methane feed) large amounts of excess combustion air (i.e., low fuel to air ratios) must be supplied to the reheat burner to compensate for the inherent ineffectiveness of co-current heat exchange. By supplying large amounts of excess air and regeneratively heating it, the heat contained in the combustion stream exhaust can be recycled back into the combustion chamber. However, this requires additional heat exchangers and results in thermodynamic losses when the excess air is eventually vented from the system. The co-current flow was originally selected because it would allow less stringent design and materials

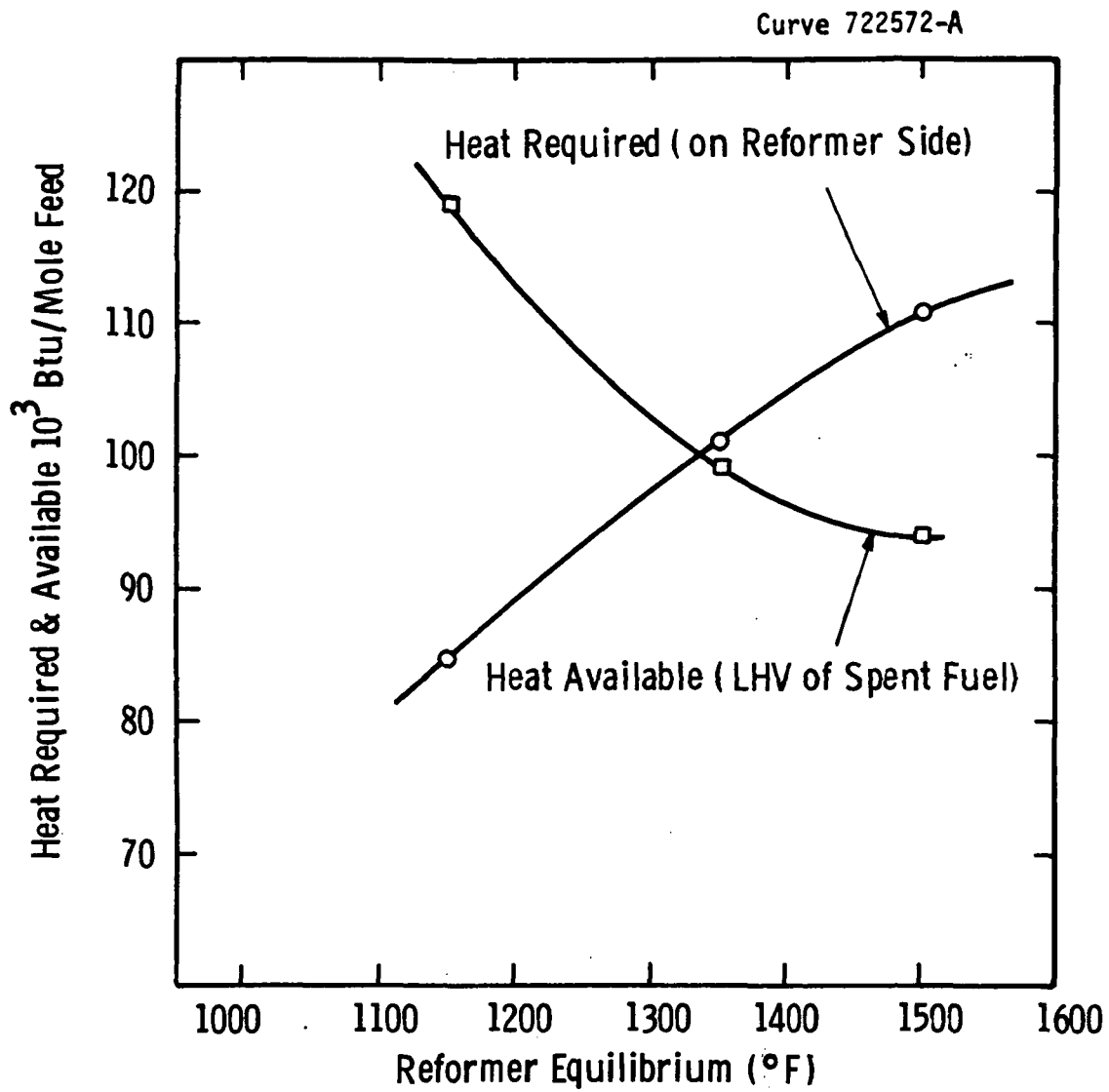


Fig. 14 — Natural gas reformer operation solely on spent fuel

requirements due to its lower average stream temperatures. However, it appears that its heat transfer/thermodynamic disadvantages are large.

An initial evaluation of a double counterflow reformer design was begun in June. Due to the much improved heat transfer effectiveness of the double counterflow design, fluids leaving the reformer are substantially lower in temperature than for the co-current design. While more heat exchange area will be required within the reformer, less external heat exchange area will be required. Preliminary design calculations have yet to be completed to compare differences in heat exchange areas between reformer configurations. The initial results for the counter-current case indicate a higher reformer equilibrium temperature (therefore a higher methane to hydrogen conversion) is possible with the same spent fuel flow rate with a combustion gas temperature limit of 1200°C.

To ensure that the CO concentration to the fuel cell is low enough to prevent poisoning of the catalyst, the shift converter must be operated in the proper temperature range to have a favorable equilibrium constant for the reaction. This can be achieved by an adiabatic shift converter where the inlet stream is at a sufficiently low temperature that adequate conversion occurs, even though the temperature increases and the equilibrium constant decreases due to the exothermic heat of reaction. Alternately, a nearly isothermal shift converter could be used. It would require internal cooling of the catalyst bed but would afford good control of the CO concentration with minimum catalyst volume. As for the reformer, the internally cooled shift reactor could utilize either co-current or counter-current flow. If the cooling flow maintains isothermal conditions, counter-current or co-current, flow will be the same. If the shift converter gas stream temperature decreases in passing through the reactor, the flows should be counter-current for maximum effectiveness. If the shift converter gas stream increases in temperature, the heat exchanger should be co-current for maximum effectiveness. Figure 15 is a qualitative plot of temperatures through the reactor for each case. For a given set of temperatures, it is

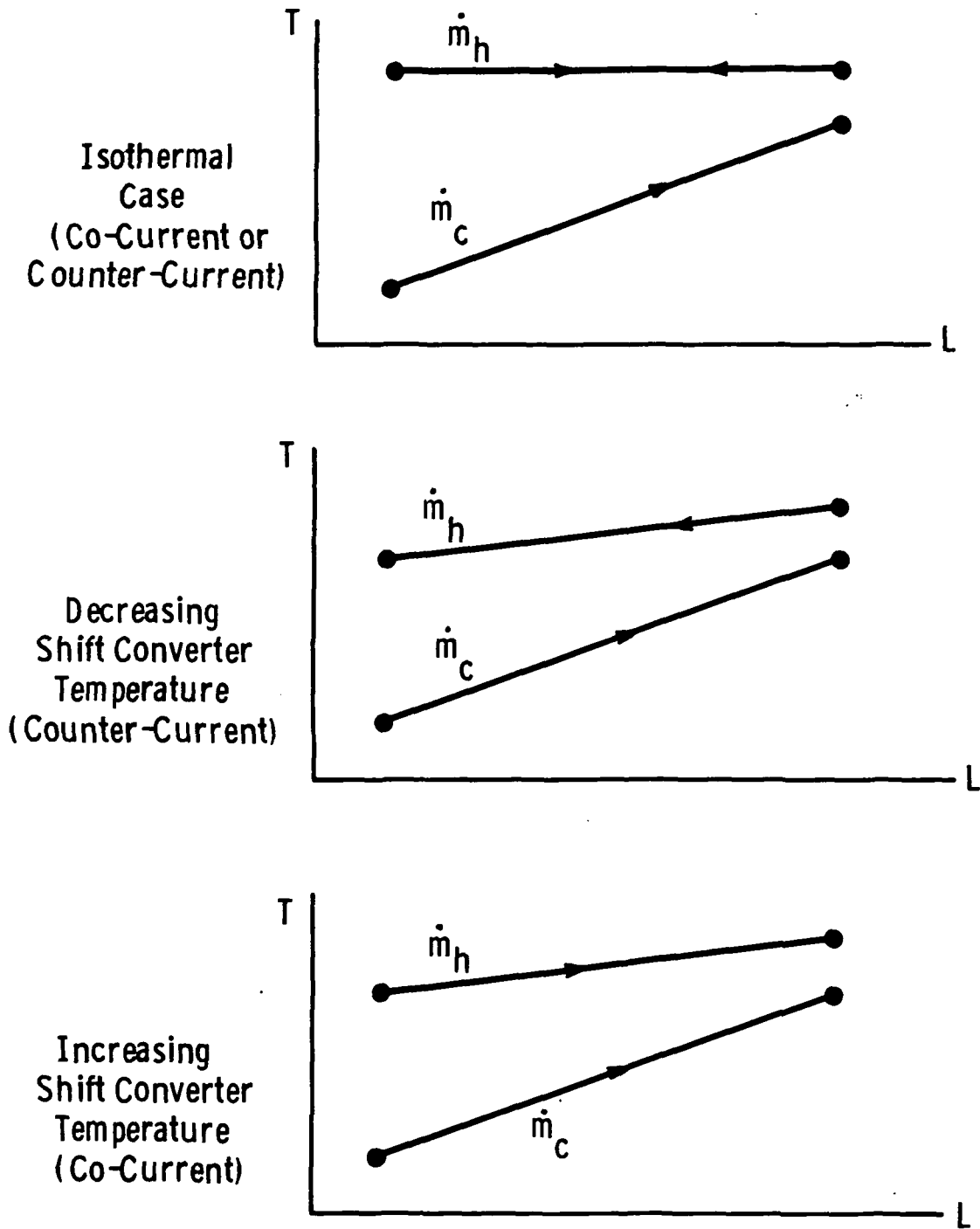


Fig. 15 — Shift converter heat exchange flow configurations for isothermal or near-isothermal operation.

desirable to design for the maximum log mean temperature difference. Further evaluation is required to determine if cooled or uncooled shift reactor design is the most cost effective for the OS/IES system.

4.3 Steam Reforming Catalyst Data Base

The methane-steam reforming experiments using Catalyst 100 were completed. These experiments were started with a catalyst dilution of 4 parts inert alumina (20 mesh) to 1 part catalyst and then changed to 25 parts inert alumina (20 mesh) to 1 part catalyst to further reduce radial temperature gradients. Both crushed (16-20 mesh) and pelleted catalysts were used. The results of these experiments are presented in Tables V through VII and Figures 16 through 18 and summarized below.

1. The use of a higher catalyst dilution ratio provides smaller radial temperature gradients. For example, at 700°C the radial temperature gradient was 17°C at a dilution ratio of 25:1 and 30°C at a dilution ratio of 4:1.
2. Since there is no significant difference in the catalyst activity between the crushed (16-20 mesh) and the pelleted catalysts, it is assumed that the catalyst pore radius is big enough to neglect the internal mass diffusion resistance for this catalyst.
3. The diffusion-free activation energy is approximately 17 kcal/gmol and the diffusion-limited activation energy is between ~6 and 9 kcal/gmol.
4. The temperature at which diffusion becomes the limiting factor lies between 550 and 620°C and is increased by a decrease in methane space velocity. Because of the complexity of the internal and external mass diffusion effects, more experiments are needed before a final conclusion is reached concerning the influence of temperature on the activity under diffusion limited conditions.
5. At low temperatures (<550°C) the water partial pressure has no effect on the reaction rate. At high temperatures (>550°C) the

TABLE V

METHANE/STEAM REFORMING AT A 4:1 CATALYST DILUTION RATIO
WITH CATALYST 100-C/20M

Inlet Mole Fraction				S/C Ratio ϕ	μ Mole CH ₄ g-sec	T _{avg} °C	Conversion α	Rate $\frac{f}{w} \left(\ln \frac{1}{1-\alpha} \right)$	Rate/atm $\frac{f}{w} \left(\ln \frac{1}{1-\alpha} \right) \div P_{CH_4}$
H ₂ O	CH ₄	H ₂	Ar		f/w*				
0.2	0.1	0.02	0.68	2	930	452	1.36×10^{-2}	12.76	127.6
		"		2	930	509	2.84	26.75	267.5
		"		2	930	564	5.80	55.47	554.7
		"		2	930	612	6.25	60.02	600.2
		"		2	930	664	9.38	91.60	916.0
		"		2	930	724	10.51	103.25	1032.5
0.4	0.1	0.02	0.48	4	930	413	0.77	7.15	71.5
		"		4	930	452	0.94	8.75	87.5
		"		4	930	508	2.77	26.16	261.6
		"		4	930	554	5.50	52.41	524.1
		"		4	930	604	6.53	62.82	628.2
		"		4	930	613	6.83	65.76	657.6
		"		4	930	659	8.10	78.60	786.0
		"		4	930	665	8.89	86.48	864.8

*f \equiv inlet CH₄ flow, 10^{-6} moles/sec

w \equiv weight of catalyst, grams

f/w \equiv inlet "space" velocity

TABLE VI

METHANE/STEAM REFORMING AT A 25:1 CATALYST DILUTION RATIO
WITH CATALYST 100-C/20M

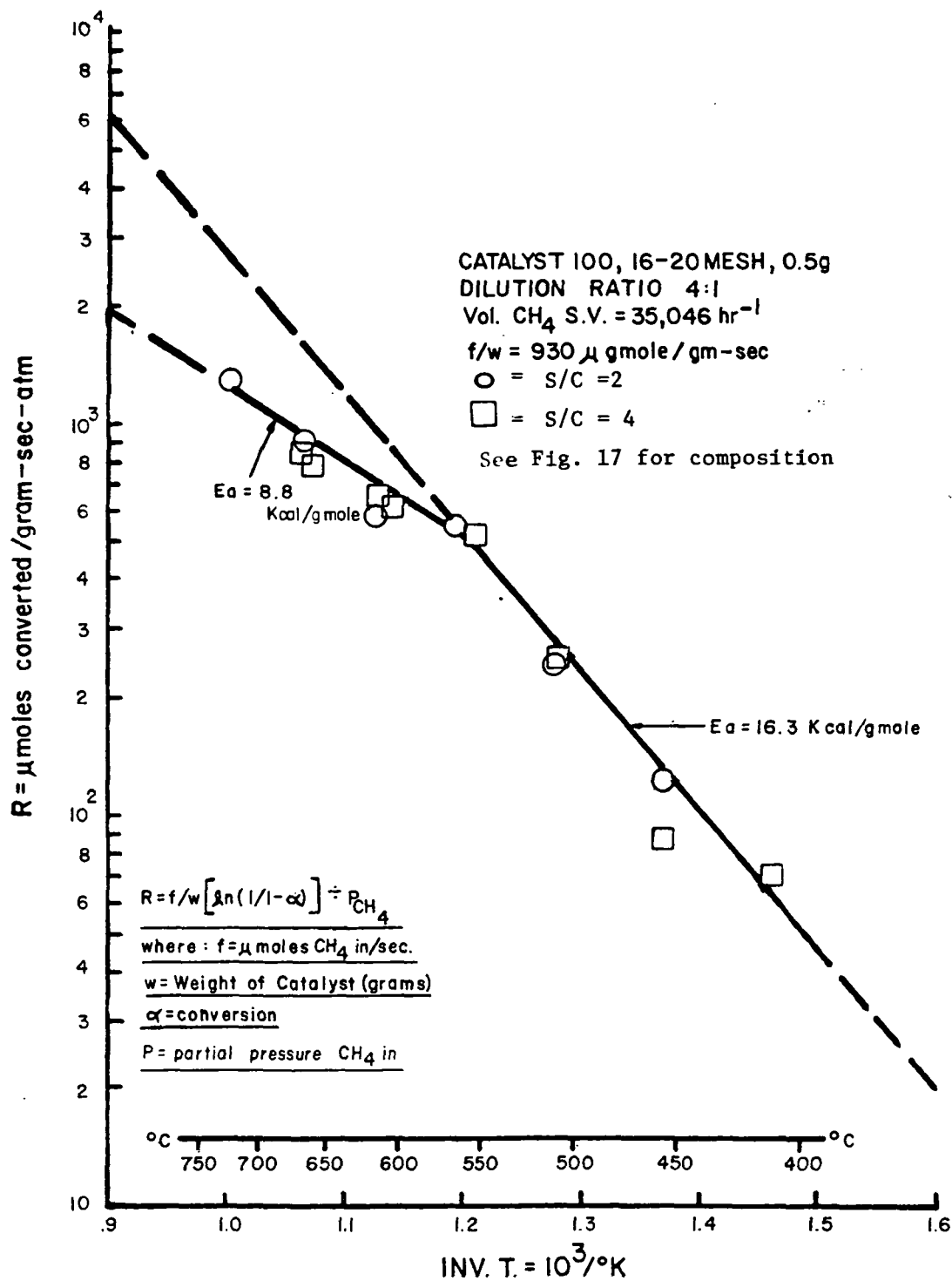
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Inlet Ratio				S/C Ratio ϕ	μ Mole CH ₄	T _{avg} , °C	Conversion α	Rate $\frac{f}{w} \left(\ln \frac{1}{1-\alpha} \right)$	Rate/atm $\frac{f}{w} \left(\ln \frac{1}{1-\alpha} \right) \div P_{CH_4}$
H ₂ O	CH ₄	H ₂	Ar		g-sec f/w				
0.2	0.1	0.02	0.68	2	930	458	0.72×10^{-2}	6.76	67.6
		"		2	930	508	1.90	17.86	178.6
		"		2	930	555	3.32	31.34	313.4
		"		2	930	653	6.30	60.49	604.9
		"		2	930	703	6.79	65.38	653.8
0.4	0.1	0.02	0.48	4	930	461	0.50	4.66	46.6
		"		4	930	509	1.78	16.70	167.0
		"		4	930	556	3.86	36.57	365.7
		"		4	930	650	7.34	70.84	708.4
		"		4	930	704	8.45	82.10	821.0
0.4	0.2	0.02	0.38	2	1860	505	1.35	25.36	126.8
		"		2	1860	556	2.20	41.27	206.4
		"		2	1860	649	4.86	92.57	462.8
		"		2	1860	699	6.83	131.59	657.9
0.6	0.2	0.02	0.18	4	1860	460	0.72	13.44	67.2
		"		4	1860	507	1.58	29.60	148.0
		"		4	1860	557	2.75	51.80	259.0
		"		4	1860	650	4.79	91.25	456.2
		"		4	1860	700	5.69	109.05	545.2
0.6	0.3	0.02	0.08	2	2790	457	0.68	19.10	63.7
		"		2	2790	507	1.38	38.70	129.0
		"		2	2790	556	2.38	67.15	223.8
		"		2	2790	650	4.03	114.73	382.4

TABLE VII

METHANE/STEAM REFORMING AT A 25:1 CATALYST DILUTION RATIO
WITH CATALYST 100-P

Inlet Ratio				S/C Ratio ϕ	M Mole CH ₄ g-sec		Conversion α	Rate $\frac{f}{w} \left(\ln \frac{1}{1-\alpha} \right)$	Rate/atm $\frac{f}{w} \left(\ln \frac{1}{1-\alpha} \right) \div P_{CH_4}$
H ₂ O	CH ₄	H ₂	Ar		f/w	T _{avg} , °C			
0.2	0.1	0.02	0.68	2	494.7	461	1.86×10^{-2}	9.28	92.8
		"		2	494.7	508		19.22	192.2
		"		2	494.7	557		33.63	336.3
		"		2	494.7	651		61.22	612.2
		"		2	494.7	701		77.73	777.3
0.4	0.1	0.02	0.48	4	494.7	458	2.35	11.78	117.8
		"		4	494.7	505	4.72	23.90	239.0
		"		4	494.7	554	7.67	39.48	394.8
		"		4	494.7	648	13.48	71.64	716.4
		"		4	494.7	697	16.31	88.10	881.0
0.4	0.2	0.02	0.38	2	989.4	459	0.55	5.48	27.4
		"		2	989.4	508	1.57	15.67	78.4
		"		2	989.4	558	2.72	27.24	136.2
		"		2	989.4	658	4.68	47.39	236.9
		"		2	989.4	704	11.50	120.83	604.1
0.6	0.2	0.02	0.38	3	989.4	459	2.10	21.04	105.2
		"		3	989.4	504	3.56	35.84	179.2
		"		3	989.4	552	6.02	61.38	306.9
		"		3	989.4	643	11.10	116.41	582.1
		"		3	989.4	693	14.09	150.30	751.5
0.6	0.3	0.02	0.08	2	1484.0	458	1.60	24.06	80.2
		"		2	1484.0	504	3.09	46.58	155.3
		"		2	1484.0	551	6.09	93.25	310.8
		"		2	1484.0	642	9.69	151.25	504.2
		"		2	1484.0	690	12.50	198.21	660.7



D1275

FIGURE 16 TEMPERATURE DEPENDENCE OF RATE CONSTANT FOR CATALYST 100 (CRUSHED) AT A DILUTION RATIO OF 4:1

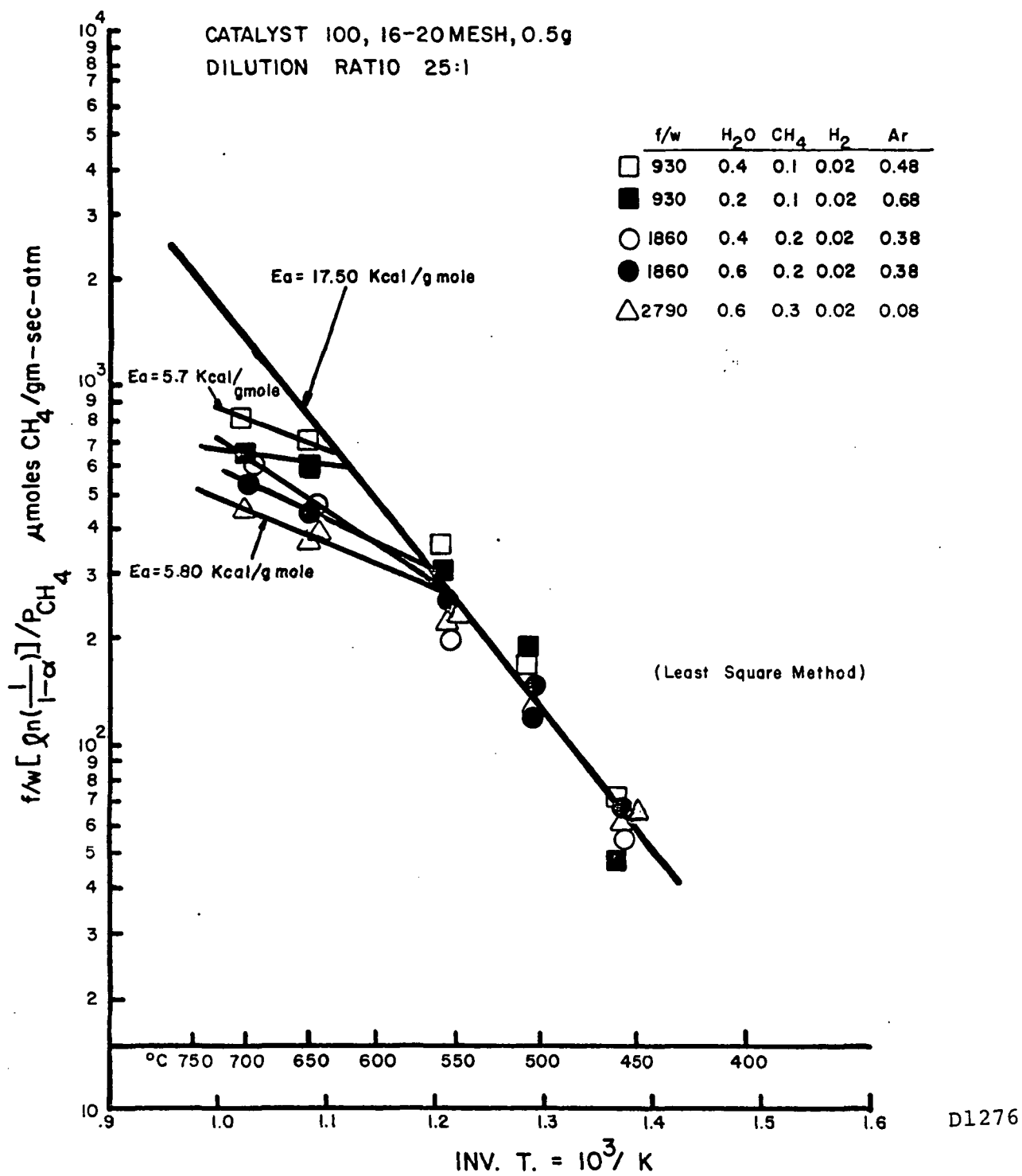
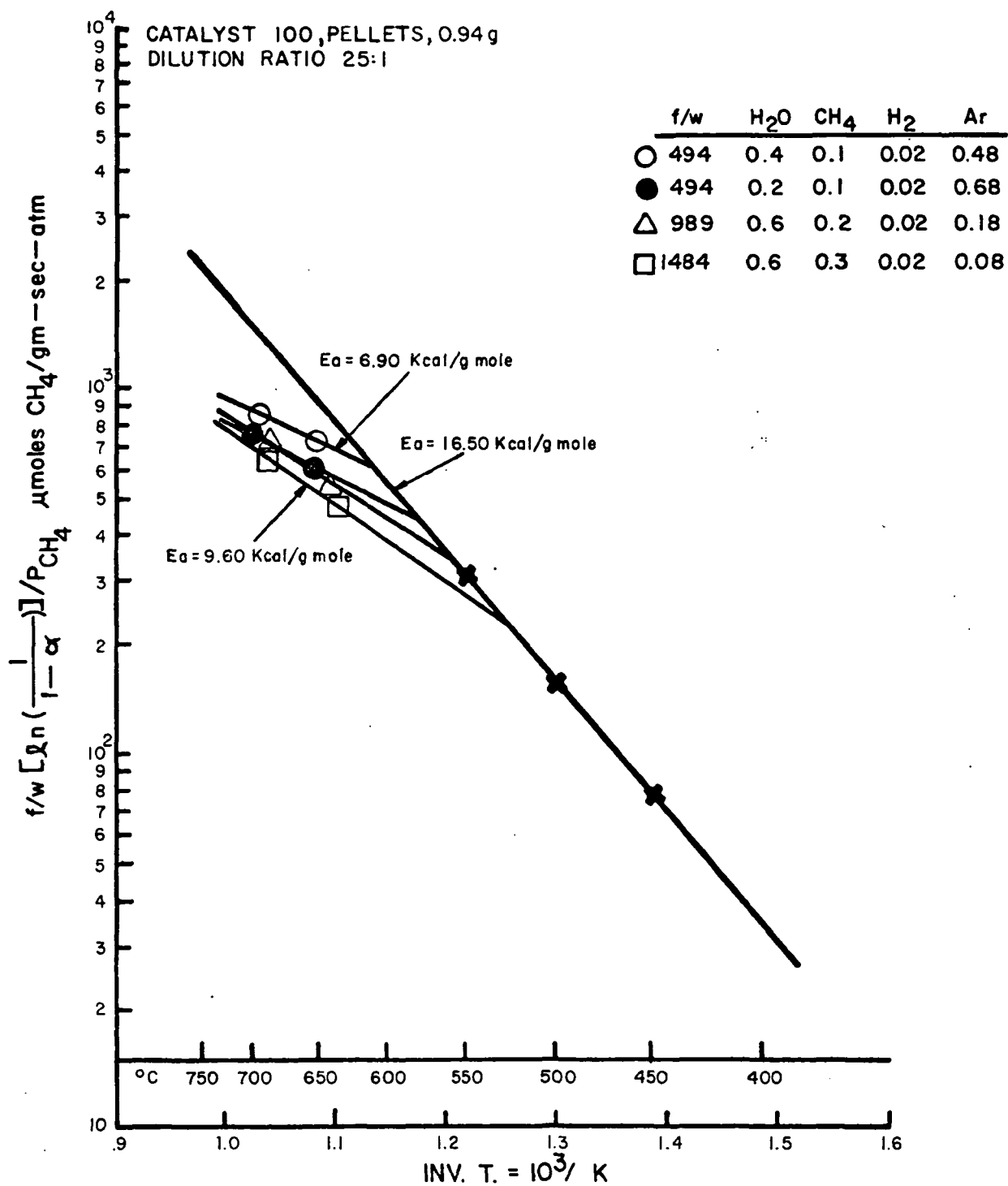


FIGURE 17 TEMPERATURE DEPENDENCE OF RATE CONSTANT FOR CATALYST 100 (CRUSHED) AT A DILUTION RATIO OF 25:1



D1277

FIGURE 18 TEMPERATURE DEPENDENCE OF RATE CONSTANT FOR CATALYST 100 (PELLETS) AT A DILUTION RATIO OF 25:1

water partial pressure has a positive effect on the reaction rate when the methane space velocity is low but has a negligible effect when the methane space velocity is high. More experimental data are required to determine the combined effects of the methane space velocity and water partial pressure.

6. At temperatures below 550°C, the reaction can be assumed to be a simple first-order reaction of methane:

$$R = k \cdot P_{CH_4}$$

The few experiments performed with United Catalyst G-91 crushed catalysts (16-20 mesh) indicate that its diffusion-free activation energy is high and the activity is low compared to Catalyst 100. The comparison of these two catalysts is shown in the following table:

CATALYST	DIFFUSION-FREE ACTIVATION ENERGY kcal/gmol	DIFFUSION-LIMITED ACTIVATION ENERGY kcal/gmol	ACTIVITY, at 500°C μ gmol CH ₄ /g sec
Catalysts 100	17	6-9	150
UC G-91	30	1	15

4.4 Ancillary Subsystem Data Base

4.4.1 Burner Development

Test Rig

Based on the assembly drawing shown in Figure 12 of the Second Quarterly Report, this quarter's efforts were on the fabrication and construction of the test rig. A milestone was met in that the burner and downstream cooling section fabrication was completed and both units were delivered. In order to assemble the unit some additional machining is required. This is being done on site and should be completed shortly.

Support facilities are nearly complete. 440 and 110 volt power lines were installed. All wiring was completed except for the hook-up to the SCR controllers. The high limit overtemperature controllers and gas temperature controllers were installed and wired. Most of the plumbing for both the gas and air lines is complete. The present schedule indicates that burner light off is likely by early August.

Test Program

A test program outline was developed for the burner, and, prior to lightoff, a more detailed test plan will be written for the guidance of the technicians operating the burner test rig. The test plan proposed for burner development was presented to the NASA Progress Meeting in May, and is included in Table VIII.

4.4.2 Water Conditioner Development

Boiler Feed Water Costs

Studies were initiated during this quarter to compare the costs for producing suitable quality reformer-boiler feed water from spent air/fuel condensate and from tap water. A number of conceptual schemes for water purification trains were investigated. Schematic diagrams

TABLE VIII
REFORMER BURNER TEST PLAN

1.0 CHECK OUT AND INITIAL DATA

1.1 FUEL

COMPOSITION: NATURAL GAS

TEMPERATURE: AMBIENT TO 95°C

FLOW: LEAN BLOW OUT TO 1650°C OUTLET TEMP.

1.2 AIR

TEMPERATURE: AMBIENT TO 250°C

FLOW: 22 KG/H (25KW) TO 50 KG/H (60KW)

1.3 DATA TO BE TAKEN

1.3.1 AIR FLOW: 25, 42, 60 KW

1.3.2 AIR TEMPERATURE: 20, 175, 250°C

1.3.3 FUEL TEMPERATURE: 20, 95°C

1.3.4 FUEL FLOW: FOR OUTLET TEMPERATURE 1200 AND 1650°C

1.3.4 COMBUSTION EFFICIENCY: THERMAL ANALYSIS TO 1200°C
GAS ANALYSIS TO 1650°C

1.4 EXPECTED RESULTS

1.4.1 OPERATIONAL PERFORMANCE OF SYSTEM

1.4.2 OPERATION OF PREHEATERS

1.4.3 BURNER CHARACTERIZATION WITH NATURAL GAS

TABLE VIII (CONTINUED)

2.0 FUEL CELL GAS CHARACTERIZATION

2.1 FUEL

COMPOSITION: CH_4 = 3.5%
 CO = 2.9
 H_2O = 7.3
 H_2 = 39.3
 CO_2 = 47.0

TEMPERATURE: MINIMUM FOR OUTLET TEMPERATURES OF
1200 AND 1650°C (425°C UPPER LIMIT)

2.2 AIR

TEMPERATURE: 315, 425, 540°C
FLOW: 22KG/H (25KW) TO 50 KG/H (60KW)

2.3 DATA TO BE TAKEN

- 2.3.1 AIR FLOW: 25, 42, 60 KW
- 2.3.2 AIR TEMPERATURE: 315, 425, 540°C
- 2.3.3 FUEL TEMPERATURE: MIN. 315, 425°C
- 2.3.4 FUEL FLOW: FOR OUTLET TEMPERATURE OF 1200 AND 1650°C
- 2.3.5 COMBUSTION EFFICIENCY: THERMAL ANALYSIS TO 1200°C
GAS ANALYSIS TO 1650°C

2.4 EXPECTED RESULTS

2.4.1 BURNER CHARACTERIZATION WITH SPENT FUEL CELL GAS

were used to document and follow changes in the systems being developed. The diagrams also served as:

1. Points of discussion for establishing the two reference systems on which to base the costs.
2. A source for identifying specific components and suppliers to be contacted for information.
3. A basis for preliminary material and heat balances, using Phase I data.
4. A reference to reflect various technical, philosophical and competitive business requirements, as they evolve.

Schematic diagrams of the water purification trains for recovered condensate and tap water are shown in Figures 19 and 20 respectively. The advantages and disadvantages of using tap water are shown in Table IX.

Due to low flow, a feed-and-bleed recirculating circuit is shown for the ion exchange portion of both trains, with flow rates ranging from 680 to 3400 kg/h. Mono mixed beds of 3100 grams and 940 grams capacities are indicated for service with water assumed to contain 0.1 gram/kg, as CaCO_3 . These yield 17 and 5 days, respectively, before renewal or replacement is needed. Longer renewal times can be achieved by adding additional resin capacity or where the anion content of the water is lower than the value which was assumed. Work is continuing to refine the two reference flow schematics and to obtain corresponding costs for producing suitable quality water.

Chlorine and Halide Removal from Tap Water

The removal of free chlorine from tap water has been investigated. Chlorine, either as Cl_2 gas or a hypochlorite (OCl^-), is used as a disinfectant in tap water. Enough chlorine is added to kill disease producing organisms, to consume organic matter present, to remove

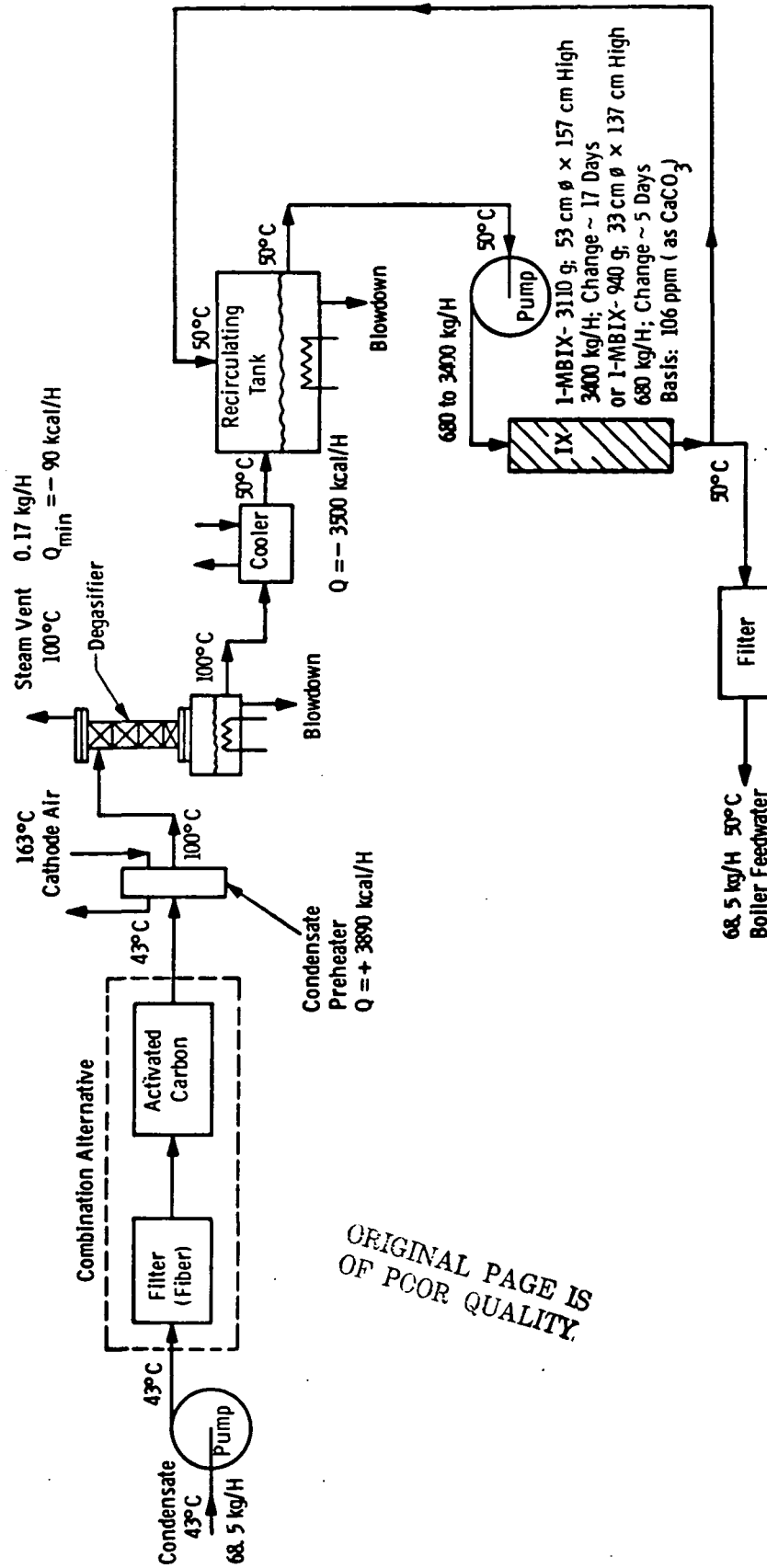


Fig. 19 - Condensate water purification train

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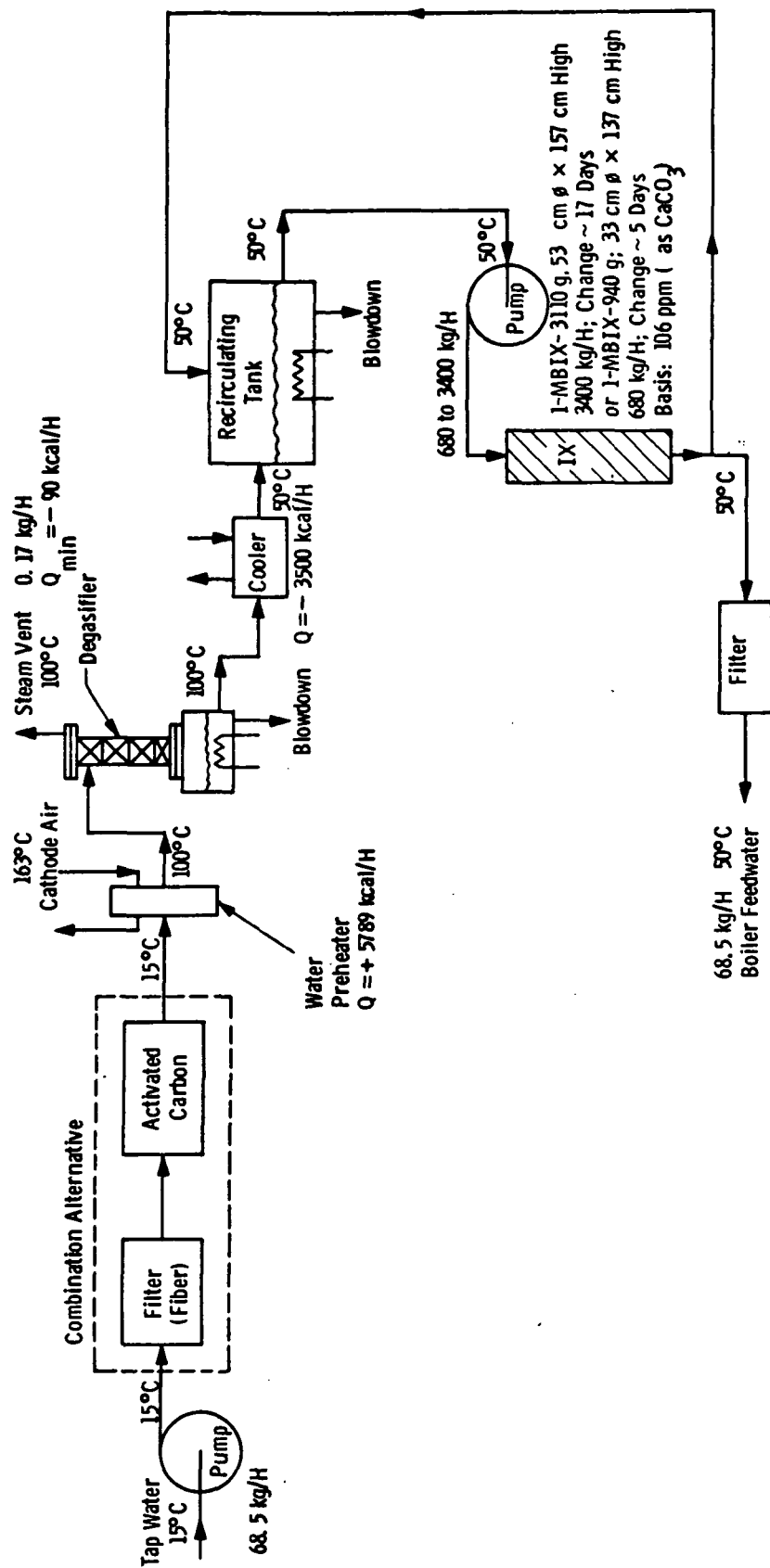


Fig. 20 - Tap water purification train

TABLE IX

TAP WATER PURIFICATION
RELATIVE TO CONDENSATE PURIFICATION

<u>ADVANTAGES</u>	<u>DISADVANTAGES</u>
1. Upstream filter and carbon bed operate at low temperature	1. Requires additional heat for water preheater.
2. Provides continuous supply of water for normal operation, start-up, faulted operation (leaks), etc.	2. Potential low level chlorine in part of train if carbon bed malfunctions
3. No H_3PO_4 concerns	3. In some areas of U.S., dissolved solids may exceed those in recovered condensate
4. Low levels for dissolved gas (CO_2 , O_2)	4. The purchase of tap water will be an additional operating expense for the system owner.
5. Potential for avoiding use of pump to transfer water to purification train.	5. The OS/IES system is dependent on an external water supply and is subject to whatever cost is involved in that connection and to whatever unreliability is introduced by that connection.

H₂S, to oxidize iron, manganese, etc., and to retain a residual. A 2 ppm Cl₂ residual is typical, but older water transmission networks may require more to maintain a positive residual at the furthest points. Activated carbon is generally the preferred method for dechlorination; chemical reducing agents can also be used (sodium sulfites or thiosulfate). In the dechlorination with activated carbon, chloride ions are produced and the carbon is consumed.

Data obtained under controlled conditions for several commercial activated carbons are available⁽¹⁾. Calculations indicate that with 0.02m³ of activated carbon, the times before a 10 ppb Cl₂ effluent break point is reached with a flow rate of 68.5 kg/h are as follows:

1. Filtrasorb 200 @ 8020 kg/h-m³ & 2 ppm Cl₂ Influent - 62 years
2. Filtrasorb 100 @ 8020 kg/h-m³ & 2 ppm Cl₂ Influent - 14 years

With 0.0085m³ of carbon at similar conditions, results are as follows:

1. Filtrasorb 200 @ 8020 kg/h-m³ & 2 ppm Cl₂ Influent - 25 years
2. Filtrasorb 100 @ 8020 kg/h-m³ & 2 ppm Cl₂ Influent - 5 years
3. Filtrasorb 100 @ 8020 kg/h-m³ & 4 ppm Cl₂ Influent - 1.7 years

Practical experience by Calgon indicates that, because of breakdown of carbon granules, increased pressure drop can result and fines can pass out of the vessel and cause problems down stream. For free chlorine they indicate that one pound of carbon will be consumed in the removal of one pound of free chlorine. At a 2 ppm Cl₂ influent level, carbon would be consumed at a rate of 0.0025m³ per year.

Private communication from a representative of Ionics indicates \$200 as a rough cost for a 0.02m³ carbon bed in a 40 cm diameter FRP tank. Filtrasorb 100 sells for \$2.16/kg and Filtrasorb 200 sells for \$2.08/kg in 27.2/kg bags for quantities less than 230 kg.

(1) Ionics, Bridgeville, PA., Cab-Iontm Product Bulletin
and Calgon, Pittsburgh, PA., Applications Bulletin

The conversion of free chlorine to chloride ion will add less than 10% additional anion load to an ion exchanger operating on water similar to that available at the R&D Labs (2ppm added to 28 ppm Cl).

Fluoride is frequently present in tap water. Natural fluoride in U.S. water ranges from 0.05 ppm in the Northeast to a high of 8 ppm in sections of the Southwest. In areas having low fluoride an adjustment is made in municipal water to a level of about 1 ppm to protect tooth enamel from cavities. Fluoride ion has the least affinity for ion exchange with an ion resin of all the halides ($F < Cl < Br < I$), but it can be removed by strong base anion resins regenerated in the hydroxide form. This is shown by Table X, which was taken from the Duolite Ion-Exchange Manual.

TABLE X

**RELATIVE AFFINITIES OF VARIOUS MONOVALENT ANIONS
FOR DUOLITE A-101D AND DUOLITE A-102D**

ION	RELATIVE AFFINITY	
	A-101D	A-102D
<i>Hydroxide (Reference)</i>	1.0	1.0
Benzenesulfonate	>500	75
Salicylate	450	65
Citrate	220	23
Iodide	175	17
Phenate	110	27
Bisulfate	85	15
Chlorate	74	12
Nitrate	65	8
Bromide	50	6
Cyanide	28	3
Bisulfite	27	3
Bromate	27	3
Nitrite	24	3
Chloride	22	2.3
Bicarbonate	6.0	1.2
Iodate	5.5	0.5
Formate	4.6	0.5
Acetate	3.2	0.5
Propionate	2.6	0.3
Fluoride	1.6	0.3

In placing activated carbon (Filtrisorb) into beds the following design parameters are recommended:

Carbon Bed Depth	76 cm (Min.)
Basis for Column Diameter	6100 kg/h-m ² (Max.) for Filtrisorb 100
	12,200 kg/h-m ² (Max.) for Filtrisorb 200
Freeboard in Bed	40% of Carbon Bed Depth (Min.)

Pressure drop ranges from 1 to 50 cm H₂O per 30 cm of bed with corresponding superficial flows of 2440 to 49,000 kg/h-m² for Filtrisorbs. Barnstead reports that the performance of carbon beds as filters, for their M-3653 unit (Witco carbon) as 100% removal above 10μ.

Combination carbon/filter units are commercially available from AMF/CUNO (Cartridge 46285-01 in various housings -5μ, 38°C limits) and Sethco Div. of Met-Pro (In-Filtrator, Carbolator 35B/7B - combined with other purification features; plating industry primary applications). Straight carbon beds are available in small sizes from Barnstead (M-3653) and Ionics (custom application) and probably others. Information on specific performance of these units is very limited.

The removal of free chlorine from tap water appears to be a relatively easy operation which is highly effective and low cost. The method also removes organics (or chlorinated organics), turbidity, color, odor and other low level contaminants at the same time. Combined filtration or using the carbon bed as a filter, is possible. However, the efficiency and effectiveness of the combination are less well defined. Replacement of the activated carbon appears to be required on a yearly basis because of potential carbon particle degradation but not loss of capacity. Equipment is available commercially which can be adapted to almost any design. Custom or in-house designs are also possible. Fluoride (and other ionic halides) can be removed from tap water with strong base anion resins regenerated in the hydroxide form.

The fluoride and chloride residual content in the purified water, although in the 10 parts per billion range, may deposit 5 to 10 grams of halogen in the shift catalyst over one year (8000 hours) of operation. This may cause intolerable degradation in shift catalyst activity. This problem will be explored with shift catalyst vendors.

4.4.3 Other Ancillary Systems Development

Heat Exchangers

Two meetings were held with heat exchanger vendors to discuss cost and availability of small low cost units for OS/IES application. A preliminary specification was given to the Heat Transfer Division of American-Standard for their review and comment. Specifically, they agreed to work with Westinghouse toward the development of low pressure drop, compact shell and tube exchangers for the below 550°C applications. The shell and tube exchanger has the potential advantage of easy maintainability relative to the brazed radiator core type of exchanger. However, their cost and size may be too great for the OS/IES application. Discussions with American-Standard and Harrison Division of General Motors will continue to resolve these questions.

Control System

As part of the OS/IES operational requirements, methods for handling demand transients must be devised. The following is a description of preliminary considerations of this requirement.

In the event of an increased electrical demand more hydrogen is required by the fuel cell. In order to supply this hydrogen, an increase in the steam/methane feed to the reformer is required and this will result in a decrease in reformer operating temperature with a resultant decrease in conversion to hydrogen unless the heat input to the catalyst bed can be increased proportionately. However, due to the transit times through the system and the fact that the fuel cell will consume more hydrogen to satisfy the load, the heating value of the spent fuel to the combustor

will be decreased. To prevent such an up power transient from disrupting cell and reformer operation and to provide adequate electrical power to meet the load, hydrogen and fuel accumulations within the piping and reactors could be utilized, natural gas could be used to augment burner fuel and/or the electric utility tie line could be used to meet sharp up power transients. This set of reformer/fuel supply transient control requirements is being addressed in the OS/IES control system definition. The use of supplemental natural gas burner fuel and utility tie line electric power may be the most cost effective option.

During this quarter, the preliminary specification for a prototype control system was released to six potential suppliers. It must be emphasized that such a complicated system is not intended for and could not be justified on a cost basis for the commercial OS/IES but would be necessary for the prototype.

It was expected that the first response from the suppliers would be questions on the specification and suggestions for a revised and final specification. There were several phone calls on minor points. Otherwise the suppliers were quite willing to bid on the preliminary specification. One question raised was on valve operations, namely could they be operated stepwise. This could create the problem of requiring properly positioned and sized surge tanks (or oversized pipe).

The plan was to receive input from each supplier and to make a preliminary evaluation by July 1. To date, only two suppliers have furnished adequate descriptions and prices of their system. These are the Hewlett Packard and the John Fluke Manufacturing Co. The Hewlett-Packard complete package totaled \$47,841.75 and the Fluke package totaled \$27,035. Some of the other suppliers sent general descriptive bulletins and Richard Peronne of Data Acquisition Systems visited us twice, once to deliver a set of descriptive bulletins. The goal now is to receive all input and complete the evaluation by August 1.

Steam Jet Ejector

A preliminary analysis of a steam jet ejector system in place of a natural gas compressor was made. Several ejector design options were reviewed, but because of the difficulty in using reference material, a definitive answer to the applicability of jet ejectors to natural gas compression in the OS/IES system must await further investigation into the ejector design curves.

An ejector (injector or eductor) is a type of compressor with no pistons, valves, rotors, or other moving parts. It consists, in this case, of a steam nozzle which aspirates the natural gas and then enters a diffuser which converts the kinetic energy of the steam gas mixture to pressure to drive the natural gas through the reformer and the balance of the system. In the present case the ejector serves the second purpose of mixing the gas and steam. If steam is available at several pressure levels, ejectors can be placed in series to provide additional boost with intermediate condensers to prevent an excessive build-up of steam content.

Design curves for single-stage ejectors are offered in the form of a nomograph by DeFrate and Hoerl in Chemical Engineering Progress, 55, Symposium Serial 21, 46 (1959). The nomograph is shown on page 6-31 of the fifth edition of the Perry and Chilton Chemical Engineers Handbook together with a brief description of its use. The design is based on the following notation:

P_{oa} - steam supply pressure (motive)

P_{ob} - gas (methane) supply (suction) pressure

P_{03} - mixture discharge pressure

A_2 - diffuser throat area

A_t - steam nozzle throat area

These result in the following dimensionless ratios, used as coordinates of the nomograph:

P_{03}/P_{ob} - compression ratio

P_{ob}/P_{oa} - suction to motive pressure ratio

W_b/W_x - entrainment ratio (gas to steam)

$A_2/A_t = A_R$ - optimum area ratio

If one knows the compression ratio and the suction to motive pressure ratio, he enters the nomograph to establish the optimum area and the entrainment ratios. If, as in our case, one wishes to find the necessary motive pressure for an entrainment ratio, (determined by the reformer steam to methane ratio), this can be done by trial and error with the curves in the handbook.

At this time the pressure drops through the system, actual flow rates, and the piping/valve layout have not been established. For an assumed 30 kPa pressure drop, more than enough motive force will be available at a steam to methane mole ratio of three if the steam is at 600 kPa gauge.

The handbook nomograph does not provide adequate information to determine the performance of a fixed ejector design with varying fluid flows. The source paper will be obtained and used to investigate off-design performance of the ejector.

TASK 5: MANAGEMENT REPORTING AND DOCUMENTATION

5.1 Supervision and Coordination

Technical Review Meetings

Two technical progress review meetings were held, one in April and one in May. Each was attended by the NASA Project Manager and other government representatives. Key members of the Westinghouse-ERC team described on-going work and participated in discussions of progress and plans.

The April meeting extended over two days. As a result of discussion on the proposed design of the enclosure for full scale stacks, a need to more closely coordinate the thermal management work and enclosure design was identified.

The May meeting included a review of the operating experience and the progress made in fabricating full scale (31 x 43 cm) Mat-1* matrices. As a result of this review, it was agreed that Mat-1 matrices will be used in all stacks subsequent to 559.

Coordinating Meeting

As a result of the discussion of the April technical progress review meeting and at the request of the NASA Project Manager, Al Meyerhoff was given the responsibility for coordinating the thermal management and enclosure design work. A meeting was held to discuss the two efforts and an outline of a plan was developed and discussed during the May meeting.

Allocated Funds

The funds allocated to this program were increased by \$490,000 (to \$1,551,000) by the NASA contract specialist.

* MAT-1 is the designation of an ERC proprietary matrix.

5.2 Documentation and Reporting

Technical Reports

The Second Quarterly Report (Jan.-March) and the April and May monthlies were submitted for NASA approval. The Quarterly was distributed and the two monthlies will be distributed when approval is received. The January and February monthly were distributed during this quarter.

Management Reports

The management reports (533M and 533P) for March, April and May were prepared and distributed according to the contract requirements.

The financial plan for the fourth quarter (533Q) was prepared and submitted.

Program Review

The overall program plan, technical accomplishments to date, and near term technical plans were described to the recently appointed DOE Program Manager during a meeting at the DOE Germantown site.

5.3 Planning

No work scheduled.

III PROBLEMS

Assembly of Stack 559 (23 cell-MK-1 design) is being delayed due to bowing and cracking of cooling bipolar plate halves. Some of the blanks for these plates were post cured prior to machining and these bowed prior to machining and were more prone to cracking during the machining process than the uncured plates which were successfully machined for Stack 556 during Phase I. Uncured blanks were then machined but these were also bowed. Some plates were successfully machined but most of them cracked prior to assembly. Efforts are underway to reclaim sufficient plates to assemble 559. Uncured blanks, which will be machined if the reclamation is unsuccessful, have been delivered to the machine shop. An investigation of the successful effort for 556 is underway and the results will be used to prevent the recurrence of this problem in future efforts to fabricate cooling plates for the test stacks. This problem will not exist once the cooling plate designs are finalized and procedures for molding the half plates are developed.

IV PLANS

TASK I: DESIGN OF LARGE CELL STACKS

Debugging of the computer program to calculate detailed flow, current density, and temperature distributions of the MK-2 design should be completed during the next quarter and the program will be verified by comparison with test data as it becomes available.

Analysis of the design of the full scale module enclosure will be continued and measurements of physical properties of the stack components will be made to support this effort as needed.

TASK 2: STACK FABRICATION

Assembly of Stack 560 (5 cell-MK-2 stack with MAT-1) should be completed during the first month (July) of the next quarter.

Based on the results of the investigation mentioned in the Problems section, a procedure for fabricating cooling plates for the test stack will be developed and documented. These procedures will then be used in fabricating cooling plates for Stacks 561 and 562 (23 cell MK-1 and MK-2 stacks respectively) which should be completed during the next quarter.

TASK 3: STACK TESTING

Based on results of the tests of Stack 558 a test plan for Stack 559 will be written and submitted to the NASA Project Manager.

Tests of crushed and pelleted United Catalyst G-91C will be completed and tests of G-90B will be initiated during the next quarter.

Evaluation of the use of an "ejector" to compress and mix the reform feed stream will continue. The paper which provided the basis for the nomograph discussed in the technical progress section will be used in this work.

An engineering specialist familiar with high temperature equipment design and manufacture has been assigned to evaluate reformer design concepts. He will assess both stress and creep rupture problems in the proposed counter current reformer configuration and will also briefly address the problems of manufacture and maintenance of the reformer. His preliminary effort will require no more than two weeks of his time. He previously worked on the ultra high temperature gas cooled nuclear reactor for NASA's Nerva Rocket and is presently a designer with the Advanced Energy Systems Division of Westinghouse.

In another effort related to the conceptual design, Dr. Kirschbaum will provide guidance to the state point work in Task 4.2 so that a flow schematic and preliminary equipment performance specifications can be derived for the subsystem conceptual design.

Task 5: Management and Documentation

5.1 Supervision and Coordination

Coordination of efforts among the task leaders and between ERC and Westinghouse will be continued.

Technical review meetings will be held at the convenience of the NASA Project Manager and presentations to and meetings with DOE personnel will be scheduled as requested.

5.2 Reporting and Documentation

The task leaders' inputs to the Technical Status Reports will be edited and the reports will be submitted to the NASA Technical Manager for patent approval. The management reports will also be prepared and submitted to the NASA Technical Manager.

This report will be distributed when approved by the NASA Project Manager.

5.3 Planning

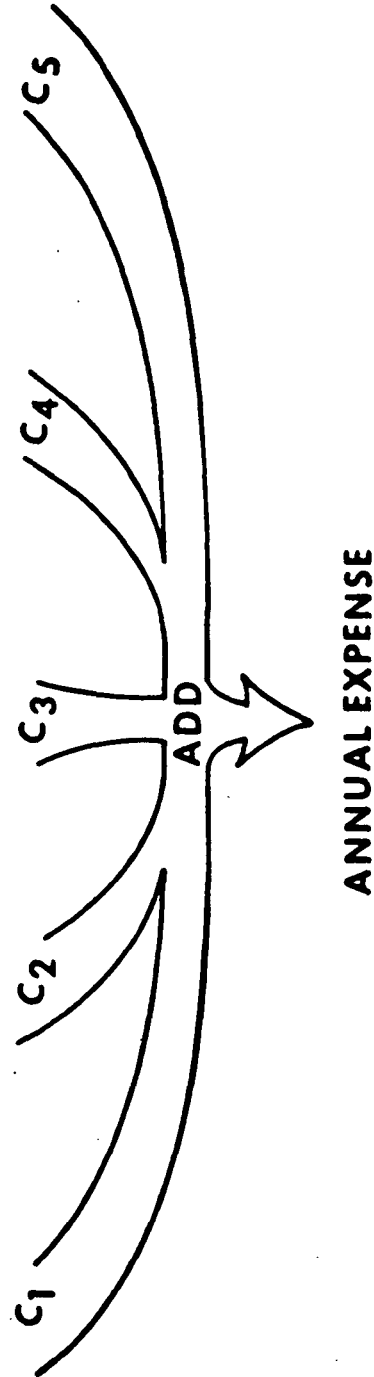
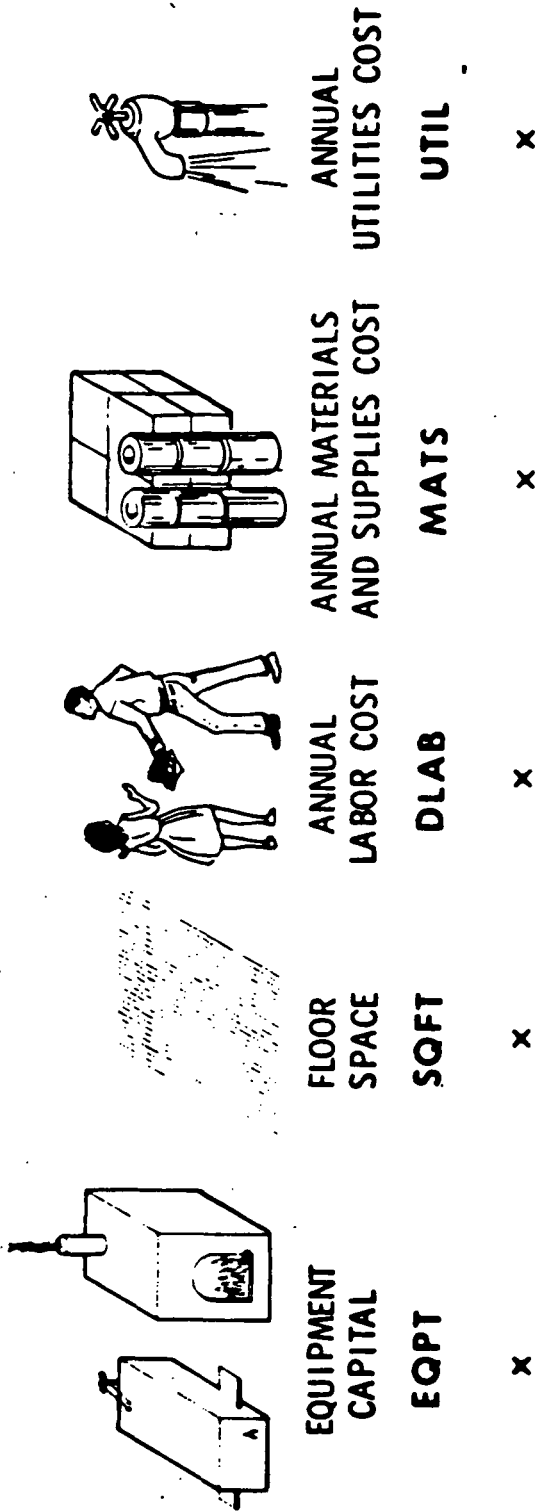
No work is scheduled for the fourth quarter.

APPENDIX A

INTERIM PRICE ESTIMATION GUIDELINES



INTERIM PRICE ESTIMATION GUIDELINES EXPENSE EQUATION



RG 12/8/77
PA&I 7



INTERIM PRICE ESTIMATION GUIDELINES

THE IPEG EQUATION FOR EXPENSES IN ANY PARTICULAR CATEGORY IS:

$$\text{ANNUAL EXPENSE} = C_1 \cdot \text{EOPT} + C_2 \cdot \text{SOFT} + C_3 \cdot \text{DLAB} + C_4 \cdot \text{MATS} + C_5 \cdot \text{UTIL}$$

WHERE THE C_i FOR THE DIFFERENT CATEGORIES ARE GIVEN IN THE TABLE AND WERE DERIVED FROM THE SAMIS MODEL, AND

- EOPT** = PURCHASE COST OF EQUIPMENT TO MAKE QUAN PER YEAR
- SOFT** = FLOOR SPACE REQUIRED BY EOPT AND ITS OPERATORS
- DLAB** = UNBURDENED, UNFRINGED COST OF DIRECT LABOR FOR QUAN
- MATS** = COST OF DIRECT MATERIALS AND SUPPLIES TO MAKE QUAN
(INCLUDES NET EFFECT OF BYPRODUCTS)
- UTIL** = COST OF DIRECT UTILITIES TO MAKE QUAN
- QUAN** = AMOUNT OF ANNUAL PRODUCTION

ONE OF THE MOST INTERESTING EXPENSE CATEGORIES IS THE TOTAL, WHICH IS ALSO THE TOTAL REVENUE. HENCE,

$$\text{PRICE} = (\text{TOTAL ANNUAL EXPENSE}) / \text{QUAN}$$



INTERIM PRICE ESTIMATION GUIDELINES

	C ₁	C ₂	C ₃	C ₄	C ₅
COEFFICIENTS OF	EQPT	SQFT	DLAB	MATS	UTIL
DIRECT EXPENSES	-	-	1.36	1.0	1.0
DIRECT LABOR (INCLUDING FRINGES)	-	-	1.36	-	-
DIRECT MATERIALS AND SUPPLIES	-	-	-	1.0	-
DIRECT UTILITIES	-	-	-	-	1.0
INDIRECT EXPENSES	0.489	96.9	0.773	0.255	0.255
INDIRECT LABOR (INCLUDING FRINGES)	-	-	0.340	-	-
INDIRECT UTILITIES	-	3.74	-	-	-
CAPITAL EXPENSES	0.310	29.2	-	-	-
PROPERTY TAXES	0.013	1.85	-	-	-
INSURANCE PREMIUMS	0.046	6.53	-	-	-
DEPRECIATION	0.143	3.55	-	-	-
INVESTMENT TAX CREDIT	-0.014	-	-	-	-
RETURN ON EQUITY (PROFIT)	0.109	15.4	-	-	-
INTEREST ON DEBT	0.013	1.85	-	-	-
START-UP, ETC. ("ONE-TIME COSTS")	0.030	22.1	0.163	0.096	0.096
CORPORATE INCOME TAXES	0.125	37.3	0.163	0.096	0.096
MISCELLANEOUS	0.025	4.8	0.107	0.063	0.063
PRICE • QUANTITY	0.489	96.9	2.133	1.255	1.255



DERIVATION OF THE IPEG PRICE ESTIMATE

REVENUES - COSTS
REVENUES = PRICE • QUANTITY
COSTS = OPERATING EXPENSES + CAPITAL REPLACEMENT + OVERHEAD
OPERATING EXPENSES = (1 + FRINGES) • LABOR + MATERIALS & SUPPLIES
+ UTILITIES
LABOR = DIRECT + INDIRECT
DIRECT = DLAB
INDIRECT = 0.25 • DLAB
MATERIALS & SUPPLIES = MATS + NEGLIGIBLE INDIRECT
UTILITIES = UTIL + 1.87 • 2.0 • SQFT
CAPITAL REPLACEMENT = 1/7 • EQPT + 1/40 • FACILITY CAPITAL
FACILITY CAPITAL = 142 • SQFT
OVERHEAD =
PROPERTY TAXES
+ INSURANCE PREMIUMS
+ PARTIAL RECOVERY OF ONE-TIME COSTS
+ INTEREST ON DEBT
+ CORPORATE INCOME TAX
+ MISCELLANEOUS
+ RETURN ON EQUITY (PROFIT)
@ 2% OF DEPRECIATED VALUE
@ 4% OF REPLACEMENT VALUE
(START-UP, INTEREST DURING
CONSTRUCTION, ETC.)
@ 12% OF DEBT CAPITAL
@ 50% OF TAXABLE INCOME
@ 5% OF TOTAL REVENUES
@ 20% OF EQUITY CAPITAL

AFTER FURTHER SUB-MODELING, THIS SYSTEM OF EQUATIONS IS SOLVED FOR PRICE.

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16. Abstract The computer code for the detailed analytical model of the MK-2 stacks was written. After reviewing available data, a decision to incorporate an ERC proprietary matrix in future stacks was made. Work on determining the mechanical behavior of the stack during thermal cycles under compression was initiated. A 5-cell stack of the MK-2 design was fabricated and tested. Designs for the next three stacks were selected and component fabrication initiated. A 3-cell stack which verified the use of wet assembly and a new acid fill procedure was fabricated and tested. Many of the components for the 2 kW test facility were received or fabricated and construction of the facility is underway in a new addition to the ERC building. The definition of fuel and water were completed and are being used in a study of the fuel conditioning subsystem which is underway. Kinetic data on several catalysts, both crushed and pellets was obtained in the differential reactor. A preliminary definition of the equipment requirements for treating tap and recovered water was developed.					
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